

AERONAUTICS

SEVENTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE

FOR AERONAUTICS

1931

INCLUDING TECHNICAL REPORTS
Nos. 365 to 400



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LETTER OF SUBMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the seventeenth annual report of the committee for the fiscal year ended June 30, 1931.

It is noted from the committee's report that the progress in aerodynamic development has been gratifying and that with recent notable additions to equipment the committee now has excellent facilities for the conduct of full-scale research on airplanes, propellers, and seaplane floats and hulls.

Attention is invited to Part V of the report presenting a summary of progress in the technical development of aircraft. With the steady improvement in the performance of aircraft, the relative importance of aviation increases as an agency of transportation and of national defense. I concur in the committee's opinion that the continuous prosecution of scientific research will provide the best assurance of further progress in the development of aircraft for all purposes.

HERBERT HOOVER.

THE WHITE HOUSE,
December 11, 1931.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 17, 1931.

MR. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to transmit herewith the Seventeenth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1931.

Gratifying progress has been made during the past year in the conduct of fundamental investigations in aeronautics at the committee's laboratories. Some of the new scientific data produced during the year have already found application in the development of military and commercial airplanes of improved performance. The research programs of the committee cover comprehensively the whole field of aircraft research, with continuing emphasis upon the major problems of increasing the safety, the reliability, and the efficiency of airplanes.

The new full-scale wind tunnel recently placed in operation will make it possible to investigate the aerodynamic characteristics and behavior of full-sized airplanes. The new N. A. C. A. Tank will make it possible for the first time to investigate the hydrodynamic characteristics of full-scale seaplane floats and hulls. These unique pieces of equipment, in conjunction with the propeller research tunnel, give the committee excellent laboratory facilities for the conduct of full-scale research and will enable it better to meet the research needs of military and of commercial aviation.

Attention is invited to Part V of the report presenting a summary of technical progress in aeronautics.
Respectfully submitted.

JOSEPH S. AMES, *Chairman.*

THE PRESIDENT,
The White House, Washington, D. C.

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JOHN F. VICTORY, *Secretary*.

SEVENTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., November 10, 1931.

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its seventeenth annual report for the fiscal year 1931.

During the past year there has been continued progress in the development of aircraft and in the extension of their use. There has been a gratifying increase in air-passenger transportation and in the scheduled miles flown by the air lines. This indicates that the public is in fact accepting aviation as a means of transportation and that as the traveling public becomes acquainted through experience with the air-transport service offered by the air lines on regular schedules and at attractive rates, the use of air transportation by the people will, in all probability, continue to increase.

The principal factor in the increasing use of air travel is, of course, speed. During the past year, there has been marked improvement in the speed of both military and commercial airplanes of new types. Where a maximum cruising speed of air transports a year ago was close to 120 miles per hour, it has been increased on single-engine transports on a few routes during the past year to 170 miles per hour. Although such high cruising speeds are exceptional at this time in air transports, such special performance or special service may well be regarded as a forerunner of normal demand and of normal service in the future.

Increase in cruising speed has been accomplished primarily through improvement in aerodynamic design by reduction in the drag of airplanes. The committee in continuing its investigation of the cowlings and cooling of air-cooled engines determined during the past year that the location of the engines in the wing of a multiengine monoplane is better than locating them either above or below the wing as is the general custom.

With each improvement in performance there is created a demand for further scientific information

that only further research will provide in order to make possible further improved performance, as, for example, through the reduction of interference drag or the general aerodynamic improvement of airplanes. In the investigation of problems of this character, it is necessary in order to obtain satisfactory results to conduct tests under full-scale conditions. Satisfactory tests involving the study of drag can not be made in flight.

During the past year the committee completed and placed in operation a full-scale wind tunnel at its laboratory at Langley Field, Va. (See figs. 1 and 2.) This is the only wind tunnel in existence large enough to test full-size airplanes. The committee also placed in operation during the past year a new towing tank for the investigation of the hydrodynamic characteristics of seaplane floats and hulls. (See fig. 3.) These two new major pieces of scientific equipment in conjunction with the propeller research tunnel (see fig. 4) for the full-scale testing of aircraft propellers, and with the equipment of the flight research laboratory for determining such aerodynamic characteristics of airplanes as can be determined in flight, give the committee excellent facilities for the full-scale testing of airplanes. Aeronautics is greatly indebted to the farsighted support of the President and of the Congress in providing necessary funds for the equipment of the committee's laboratory and for the conduct of its scientific investigations.

The facilities of the committee are used for the conduct of researches requested by the Army and Navy air organizations and also to meet the needs of commercial aviation. To determine the needs of commercial aviation the committee holds an annual conference with representatives of the aircraft industry and the suggestions received are considered by the various technical subcommittees in formulating research programs. These programs are comprehensive in scope and embrace problems of military, naval, commercial, and privately owned airplanes, and of airships. Special emphasis has for years been placed on the development of means to obtain greater control of an

airplane at low speeds incident to taking off and landing, with a view to increasing safety and reliability. In the design of military airplanes, speed and high performance, especially in military maneuvers in which great strains are imposed on the structure, are of the greatest importance, while in the design of commercial and privately owned airplanes, safety and reliability are of greater relative importance.

From the standpoint of the development of the aircraft industry, the most difficult problem is the development of a satisfactory airplane for private use. Such an airplane should not only be safe and reliable, but also economical in first cost and in cost of maintenance and operation. The committee, while devoting much attention to this general problem, has also recognized the desirable features of certain types, notably the autogiro and airplanes fitted with slots and flaps. Examples of these types have been obtained by the committee for the conduct of investigations in this field. Intensive study has also been made of the conventional type of airplane with controls and landing gear so modified as to simplify the problem of taking off and landing, and of maneuvering incident thereto.

Progress as made determines largely the trend of design and of the demand for further information along the same line. The new equipment of the committee for full-scale research is especially adapted to solve the fundamental problem of safety in aeronautics. Although the specific problems of military and of commercial aircraft are different, the solution for one is usually helpful for the other, and the research programs of the committee are so arranged as to yield

the maximum of results for both types from a given investigation.

This annual report is submitted in five parts. Part I describes the organization of the committee, states its functions, outlines the facilities available under the committee's direction for the conduct of scientific research in aeronautics, explains the activities and growth of the Office of Aeronautical Intelligence in the collection, analysis, and dissemination of scientific and technical data, and presents a financial report of expenditures during the fiscal year ended June 30, 1931.

In Part II of this report the committee describes its miscellaneous activities, including the study of aircraft accidents, the consideration of aeronautical inventions and designs, its relations with the aircraft industry, and its cooperation with other governmental agencies.

In Part III the committee presents reports on the major results of its fundamental work in the form of reports of its standing technical subcommittees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation, which include statements of the organization and the functions of each and of the progress of investigations conducted under their general cognizance in governmental and private laboratories.

In Part IV the committee presents summaries of the technical reports published during the past year, and enumerates by title the technical notes, technical memorandums, and aircraft circulars issued.

In Part V the committee presents a summary of progress in aircraft development.

PART I

ORGANIZATION

FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151). The organic act charged the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee under its organic act, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of fundamental problems submitted by the War and Navy Departments with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air organizations

and other branches of the Government and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

By act of Congress approved July 2, 1926, and amended March 3, 1927 (U. S. C., Supp. IV, title 10, sec. 310r), the committee was given an additional function. This legislation created and specified the functions of an aeronautical patents and design board, consisting of an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce, and provided that upon favorable recommendation of the National Advisory Committee for Aeronautics the patents and design board shall determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government. The legislation provided that designs submitted to the board should be referred to the National Advisory Committee for Aeronautics for its recommendation, and this has served to impose upon the committee the additional duty of considering on behalf of the Government all aeronautical inventions and designs submitted.

ORGANIZATION OF THE COMMITTEE

In accordance with the provisions of the act of Congress establishing the committee, as amended by act approved March 2, 1929 (U. S. C., Supp. IV, title 50, sec. 151a), the National Advisory Committee for Aeronautics consists of 15 members appointed by the President, as follows: Two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than eight additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

On May 21, 1931, Capt. John H. Towers, United States Navy, submitted his resignation as a member of the committee because of his relief from duty as assistant chief of the Bureau of Aeronautics of the Navy Department and assignment to duty with the fleet. Under date of May 23, 1931, the President appointed Capt. Arthur B. Cook, United States Navy, to succeed Captain Towers as a member of the committee. Captain Cook is also Captain Tower's successor as assistant chief of the Bureau of Aeronautics. He executed the oath of office as a member on June 3, 1931.

On October 18, 1931, the committee lost one of its original members through the death of Dr. Samuel W. Stratton, and under date of November 6, 1931, the President appointed as his successor on the committee Col. Charles A. Lindbergh. Colonel Lindbergh will also serve as a member of the executive committee.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 23, 1930, and that held on October 22, 1931.

The organization of the committee is as follows:

- Joseph S. Ames, Ph. D., chairman, president of Johns Hopkins University, Baltimore, Md.
- David W. Taylor, D. Eng., vice chairman, Washington, D. C.
- Charles G. Abbot, Sc. D., Secretary of the Smithsonian Institution.
- George K. Burgess, Sc. D., Director of the Bureau of Standards.
- Capt. Arthur B. Cook, United States Navy, Assistant Chief of the Bureau of Aeronautics, Navy Department.
- William F. Durand, Ph. D., professor emeritus of mechanical engineering, Stanford University, Calif.
- Maj. Gen. James E. Fechet, United States Army, Chief of the Air Corps.
- Harry F. Guggenheim, M. A., American ambassador to Cuba.
- Col. Charles A. Lindbergh, LL. D., New York City.
- William P. MacCracken, jr., Ph. B., Washington, D. C.
- Charles F. Marvin, M. E., Chief of the Weather Bureau.
- Rear Admiral William A. Moffett, United States Navy, Chief of the Bureau of Aeronautics, Navy Department.
- Brig. Gen. Henry C. Pratt, United States Army, chief of the matériel division, Air Corps.
- Edward P. Warner, M. S., editor of "Aviation."
- Orville Wright, Sc. D., Dayton, Ohio.

DEATH OF DR. SAMUEL W. STRATTON

In the death of Dr. Samuel W. Stratton in Boston on October 18, 1931, the committee lost one of the original 12 members appointed by President Wilson in 1915. In cooperation with the late Dr. Charles D. Walcott, Doctor Stratton was instrumental in bringing about the enactment by Congress of legislation which created the committee in 1915 and exerted a marked influence on the development of the committee's organization. For 15 years he was chairman of the important subcommittee on power plants for aircraft, and for seven years, from 1916 to 1923, he was secretary of the National Advisory Committee for Aeronautics. At the annual meeting of the entire committee held on October 22, 1931, the committee expressed its sense of loss in a resolution which was spread upon its minutes and copies of which were sent to the family of Doctor Stratton.

MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held on April 23, 1931, at the committee's headquarters in Washington, and the annual meeting on October 22, 1931, also at the committee's headquarters. At these meetings the recent progress in aeronautical research was reviewed and some of the principal problems of aeronautics were discussed. Administrative reports of the secretary, Mr. John F. Victory, and of the director of the Office of Aeronautical Intelligence, Dr. Joseph S. Ames, were also submitted.

At both the annual and semiannual meetings detailed reports of the research work being conducted by the committee at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., were presented, and charts and photographs were exhibited showing the methods used and the results obtained in the more important investigations.

The election of officers was the concluding feature of the annual meeting. The officers of the committee were reelected for the ensuing year, as follows: Chairman, Dr. Joseph S. Ames; vice chairman, Dr. David W. Taylor; chairman executive committee, Dr. Joseph S. Ames; vice chairman executive committee, Dr. David W. Taylor.

THE EXECUTIVE COMMITTEE

For the purpose of carrying out the work of the advisory committee the regulations provide for the election annually of an executive committee, to consist of seven members and to include in addition any member of the advisory committee not otherwise a member of the executive committee but resident in or near Washington and giving his time wholly or chiefly

to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.
 David W. Taylor, D. Eng., vice chairman.
 Charles G. Abbot, Sc. D.
 George K. Burgess, Sc. D.
 Capt. Arthur B. Cook, United States Navy.
 Maj. Gen. James E. Fechet, United States Army.
 Col. Charles A. Lindbergh.
 William P. MacCracken, jr.
 Charles F. Marvin, M. E.
 Rear Admiral William A. Moffett, United States Navy.
 Brig. Gen. Henry C. Pratt, United States Army.
 Edward P. Warner, M. S.
 Orville Wright, Sc. D.

The executive committee, in accordance with general instructions of the advisory committee, performs the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. The total paid personnel of the committee numbered 306 employees on June 30, 1931, comprising 44 in Washington, 259 at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., and 3 at the office of the technical assistant in Europe, Paris, France. General responsibility for the execution of the policies and the direction of the activities approved by the executive committee is vested in the director of aeronautical research, Mr. George W. Lewis. He has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The secretary, Mr. John F. Victory, is ex officio secretary of the executive committee, directs the administrative work of the organization, and exercises general supervision over the expenditures of funds and the employment of personnel.

SUBCOMMITTEES

In order to facilitate the conduct of its work, the executive committee has organized a number of standing committees, with subcommittees in some instances to cover the general field more effectively. During the past year the executive committee, believing that changes in its needs had occurred which should be met by changes in its subcommittees, effected a reorganization.

In this reorganization the committee on governmental relations was discharged; the subcommittee on aeronautical research in universities of the committee

on aerodynamics was discontinued because it was believed that the continuation of its work was being provided for by other agencies; the subcommittee on woods and glues and the subcommittee on coverings, dopes, and protective coatings of the committee on materials for aircraft were discharged and in their stead a new subcommittee on miscellaneous materials was established; and the subcommittee on problems of communication of the committee on problems of air navigation was discontinued because of the overlapping of its functions with the work of a committee of the aeronautics branch of the Department of Commerce.

In addition, a temporary subcommittee on research program on monocoque design has been established under the subcommittee on aircraft structures. The executive committee has recently authorized also the organization of a standing subcommittee on methods and devices for testing aircraft materials and structures as an additional subcommittee of the committee on materials for aircraft.

The standing committees of the executive committee, with their subcommittees, are at present as follows:

Aerodynamics—

Subcommittee on airships.

Power plants for aircraft.

Materials for aircraft—

Subcommittee on metals.

Subcommittee on aircraft structures—

Temporary subcommittee on research program on monocoque design.

Subcommittee on miscellaneous materials.

Subcommittee on methods and devices for testing aircraft materials and structures.

Problems of air navigation—

Subcommittee on instruments.

Subcommittee on meteorological problems.

Aircraft accidents.

Aeronautical inventions and designs.

Publications and intelligence.

Personnel, buildings, and equipment.

The organization and work of the technical committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation are covered in the reports of those committees in Part III of this report, while the activities of the committee on aircraft accidents and the committee on aeronautical inventions and designs are included in Part II under the subjects of the study of aircraft accidents and the consideration of aeronautical inventions, respectively.

Statements of the organization and functions of the administrative committees on publications and intelligence, and personnel, buildings, and equipment follow:

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE FUNCTIONS

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the Office of Aeronautical Intelligence.
4. Supervision of the committee's foreign office in Paris.
5. The collection and preparation for publication of the technical reports, technical notes, technical memorandums, and aircraft circulars of the committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Prof. Charles F. Marvin, vice chairman.
Miss M. M. Muller, secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

FUNCTIONS

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and offices.
3. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

ORGANIZATION

Dr. Joseph S. Ames, chairman.
Dr. David W. Taylor, vice chairman.
John F. Victory, secretary.

QUARTERS FOR COMMITTEE

The headquarters of the National Advisory Committee for Aeronautics are located at the rear of the eighth wing, third floor of the Navy Building, Constitution Avenue and Eighteenth Street NW., Washington, D. C., in close proximity to the Army and Navy air organizations. This space, totaling 8,914 square feet, has been officially assigned for use of the committee by the Public Buildings Commission. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, Langley Field,

Hampton, Va., and the office of the technical assistant in Europe, located at the American Embassy in Paris.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories are utilized, as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The Langley Memorial Aeronautical Laboratory is operated under the direct control of the committee. It is located at Langley Field, Va., on a plot of ground set aside by the War Department for the committee's use. The laboratory was started in 1916 coincident with the establishment of Langley Field.

The laboratory is organized with seven divisions, as follows: Aerodynamics division, power plants division, hydrodynamics division, physical research division, technical service division, flight operations division, and property and clerical division. The laboratory is under the immediate direction of an engineer in charge, Mr. Henry J. E. Reid, subject to the general supervision of the officers of the committee.

During the past year the construction of the full-scale wind tunnel and of the seaplane channel were completed. The new wind tunnel has an oval-shaped throat, 60 by 30 feet, which permits the testing of full-size airplanes. This tunnel was placed in operation during the sixth annual aircraft engineering research conference on May 27, 1931. Since then studies have been made of the flow conditions and several tests on full-size airplanes have been made. The tests made thus far have indicated that the operation of the tunnel will be satisfactory and that it will prove to be a valuable tool for studying the characteristics of full-size airplanes.

During the same conference the new seaplane channel, or N. A. C. A. Tank, as it is now officially designated, was placed in operation. This tank has a channel length of 2,020 feet and a width of 24 feet, and the carriage and test equipment are capable of towing large models of seaplane floats at speeds up to about 60 miles per hour. Up to the present time the work with this tank has been mainly confined to calibration and assembly of instrumental equipment for towing models. The preliminary tests of seaplane floats have indicated that this tank, which includes several novel features, will operate entirely satisfactorily.

In accordance with the Army's program for making military improvements at Langley Field, it will be necessary to remove the committee's present hangar, and therefore the construction of a new permanent

brick hangar was started during the past summer. This hangar will contain, in addition to the repair shop and facilities for taking care of airplanes used in flight, offices for the flight research staff.

Other less extensive additions to the equipment of the laboratory have included: A new spray-combustion apparatus, with which it is possible to photograph the spray and its combustion in a compression-ignition-engine cylinder; equipment for studying the cooling of finned cylinders, such as are used in aircraft engines; a sound analyzer by which it is possible to measure the sound intensities at various frequencies in connection with the study of aircraft noises. Two aircraft have also been added, namely, the McDonnell airplane, which is being used for the study of the effect of slots and flaps on the control at large angles of attack and on the performance of the airplane, and the autogiro, which was recently purchased in order to study the possibilities of this form of aircraft.

There are at present 11 structures comprising the Langley Memorial Aeronautical Laboratory, as follows:

1. A research laboratory building containing administrative offices, technical library, physics laboratory, photographic laboratory, and headquarters of the various divisions.

2. An atmospheric wind-tunnel building, in which the 5-foot wind tunnel of a standard closed-throat type has been replaced by more modern equipment. In the space formerly required by the 5-foot tunnel has been built a modern closed-return tunnel with an open rectangular throat 7 by 10 feet and a vertical tunnel with closed return and an open throat 5 feet in diameter. These two pieces of equipment are to be used in a comprehensive study of the problems of control and spinning characteristics of an airplane. In addition to the above equipment the building now houses a 6-inch open-throat wind tunnel for instrument and wind-tunnel studies and a 6-inch refrigerated tunnel for the study of ice formation on aircraft. More efficient use of space has also provided room for a workshop and office for the staff operating the tunnels.

3. A variable-density wind-tunnel building, housing the variable-density wind tunnel and a jet-type high-speed wind tunnel which utilizes the waste air from the variable-density wind tunnel.

4 and 5. Two engine dynamometer laboratories of a semipermanent type equipped to carry on investigations in connection with power plants for aircraft. In addition to the usual dynamometer equipment and single-cylinder test engines for studying both carbureted and Diesel-oil engines, there is equipment suited to the study of superchargers and the cooling of engine cylinders, and special high-speed photographic equipment for the study of fuel sprays.

6. A service building containing an instrument laboratory, drafting room, machine shop, woodwork- ing shop, and storeroom.

7. A propeller research tunnel, in which tests may be made in a 20-foot air stream at 100 miles per hour. This equipment permits the full-scale testing of propellers, fuselages, and landing gears.

8. An airplane hangar with a repair shop and facilities for taking care of airplanes used in flight research. This will be replaced by a new hangar, as stated above.

9. A combination heating plant, storehouse, and garage.

10. A new full-scale wind tunnel, described above.

11. A new N. A. C. A. tank, described above.

Items 1, 2, 3, 4, 5, 6, and 9 are located on plot 16. Items 7, 10, and 11 are located within two blocks of the laboratory headquarters, and item 8 is located on the flying field.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of the Langley Memorial Aeronautical Laboratory as an efficient research organization numbering 259 employees at the close of the fiscal year 1931. The work of the laboratory is conducted without interference with military operations at the field. In fact, there is a splendid spirit of cooperation on the part of the military authorities, who by their helpfulness in many ways have aided the committee materially in its work.

THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work conducted in all parts of the world, to the military and naval air organizations, aircraft manufacturers, educational institutions, and others interested. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed, classified, and brought to the special attention of the subcommittees having cognizance and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable and distributed upon request. Confidential bulletins and reports are not circulated outside of Government channels.

The records of the committee show that there has been a continuous increase in the distribution of technical publications. During the year 12,817 written

requests for reports were received in addition to a large number of telephone and personal requests and 72,080 reports were distributed upon request.

The technical publications were distributed as follows:

Committee and subcommittee members.....	5,229
Langley Memorial Aeronautical Laboratory..	2,719
Paris office of the committee.....	6,986
Army Air Corps.....	2,587
Naval Air Service, including Marine Corps..	3,797
Manufacturers.....	18,825
Educational institutions.....	17,120
Bureau of Standards.....	495
Miscellaneous.....	54,929
Total distribution.....	112,687

The above figures include the distribution of 34,206 technical reports, 26,272 technical notes, 32,380 technical memorandums, and 10,762 aircraft circulars of the National Advisory Committee for Aeronautics. Part IV of this report presents the titles of the publications issued during the past year, the distribution of which is included in the foregoing figures.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters at the American Embassy in Paris. It is his duty to visit the Government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country but more especially advance information as to work in progress and technical data not prepared in printed form, which would otherwise not reach this country. John Jay Ide, of New York, has served

as the committee's technical assistant in Europe since April, 1921.

FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1931, as carried in the independent offices appropriation act approved April 19, 1930, was \$1,306,000. Of this amount \$7,000 was later transferred to the appropriation for printing and binding, fiscal year 1931, by the second deficiency act, fiscal year 1931, approved March 4, 1931, to provide funds for the increasingly large number of technical reports being issued by the committee. This left a balance of \$1,299,000 in the general appropriation, under which the committee reports expenditures and obligations during the year amounting to \$1,173,014.74, itemized as follows:

Personal services.....	\$617,731.24
Supplies and materials.....	40,083.23
Communication service.....	1,994.42
Travel expenses.....	14,214.49
Transportation of things.....	1,604.99
Furnishing of electricity.....	16,183.66
Rent of office (Paris).....	960.00
Repairs and alterations.....	38,973.05
Special investigations and reports.....	53,500.00
Equipment.....	326,873.17
Structures and parts.....	59,995.59
Expenditures.....	1,173,014.74
Unobligated balance.....	125,985.26
Total, general appropriation.....	1,299,000.00

The appropriation for printing and binding for 1931 was \$15,000, which, with the \$7,000 transferred from the general appropriation, made available the amount of \$22,000, out of which \$21,982.67 was expended.

The appropriations for the fiscal year 1932 total \$1,051,070.

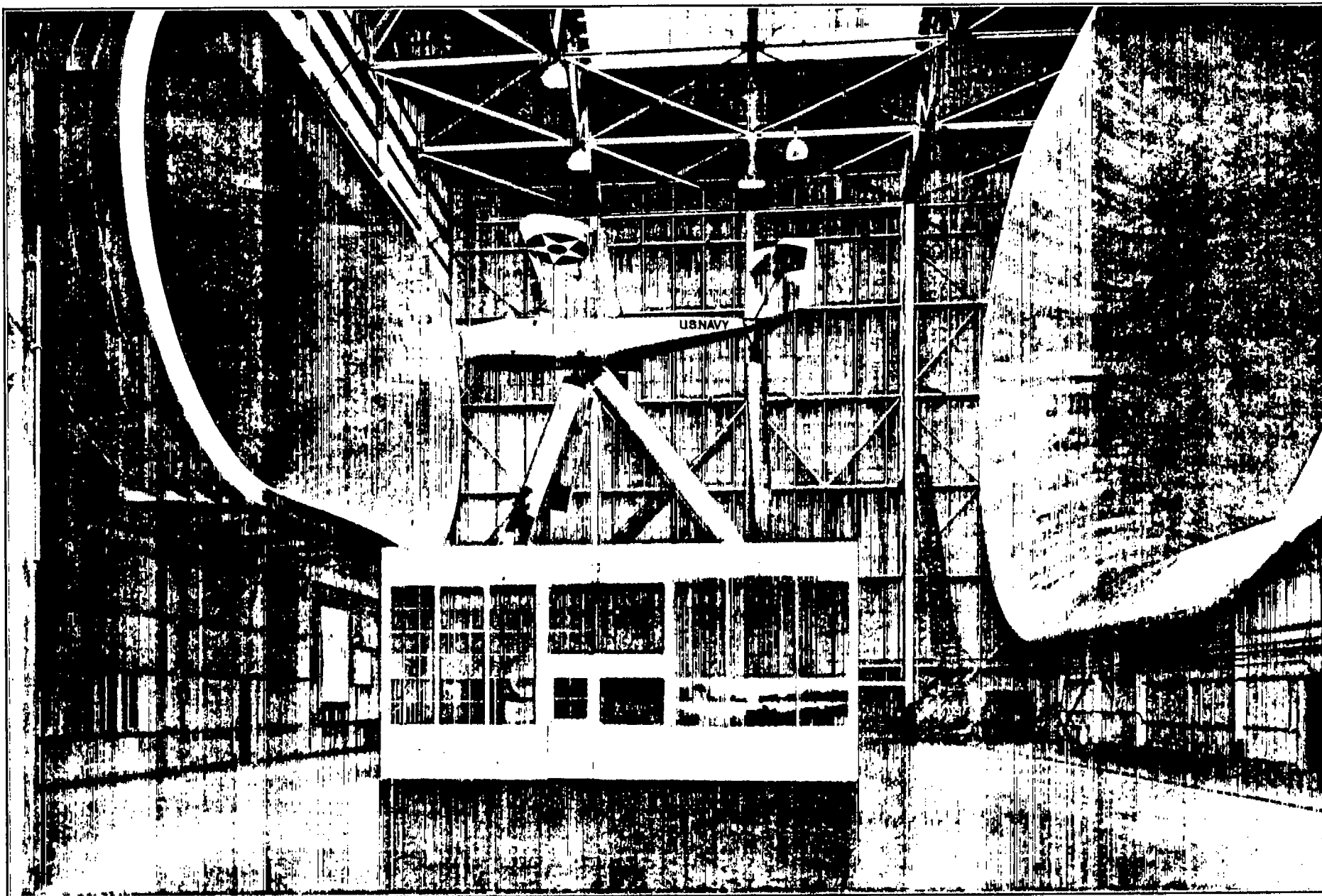


FIGURE 1.—FULL-SCALE WIND TUNNEL

FOR INVESTIGATION OF AERODYNAMIC CHARACTERISTICS OF MILITARY AND COMMERCIAL AIRPLANES. THE AIRPLANE IS SUPPORTED ON A 6-COMPONENT BALANCE BY MEANS OF STRUTS IN THE CENTER OF AN AIR STREAM 60 FEET WIDE BY 30 FEET HIGH AND HAVING A VELOCITY OF 112 MILES PER HOUR. THE BOUNDARIES OF THE AIR STREAM ARE CONFINED BY THE ENTRANCE AND EXIT CONES SHOWN.

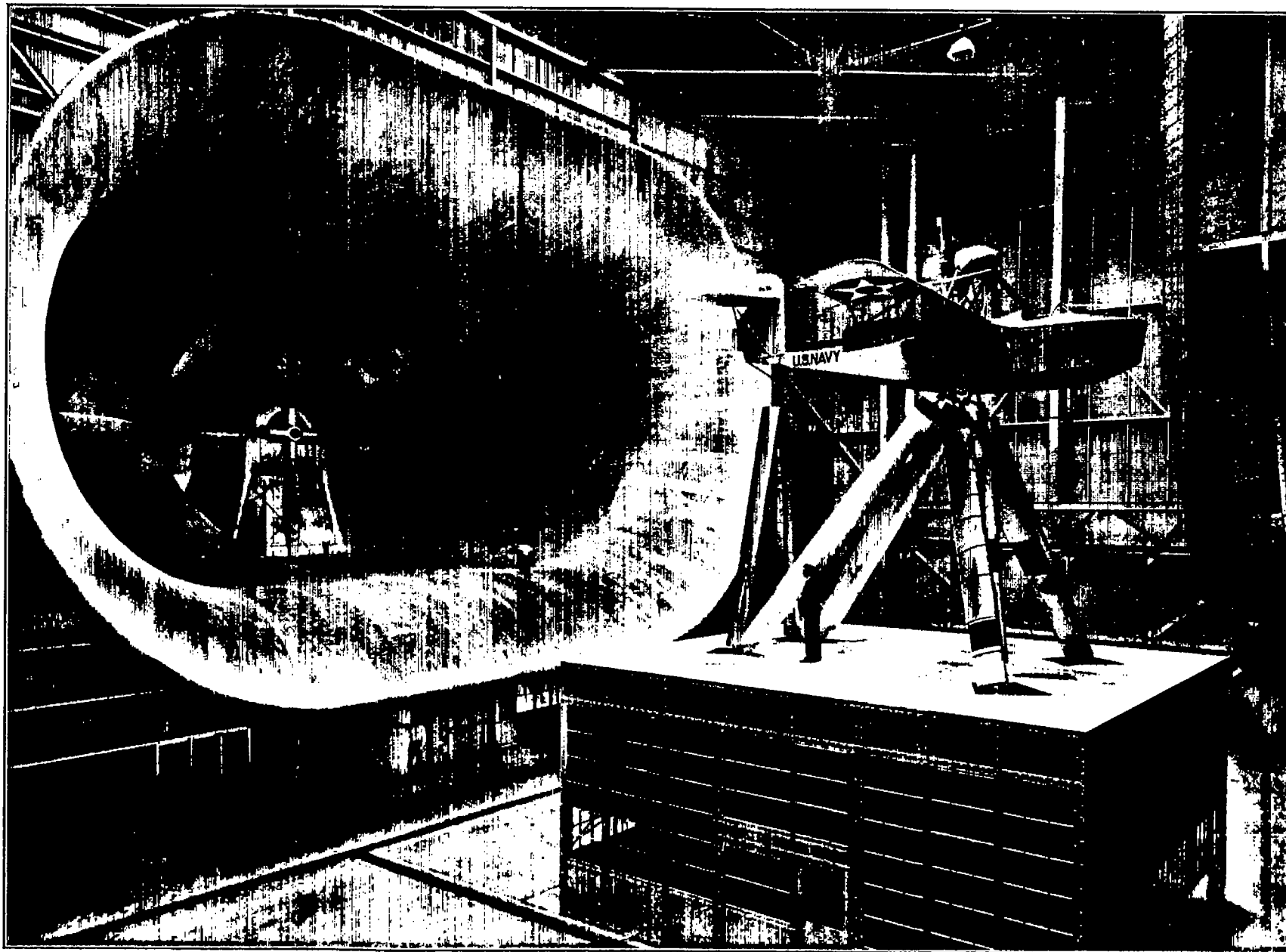


FIGURE 2.—FULL-SCALE WIND TUNNEL

SHOWING METHOD OF ATTACHMENT OF AIRPLANE TO BALANCE SUPPORTS AND ONE OF THE 4-BLADE 35½-FOOT PROPELLERS. EACH PROPELLER IS OPERATED BY A 4,000-HORSEPOWER ELECTRIC MOTOR.

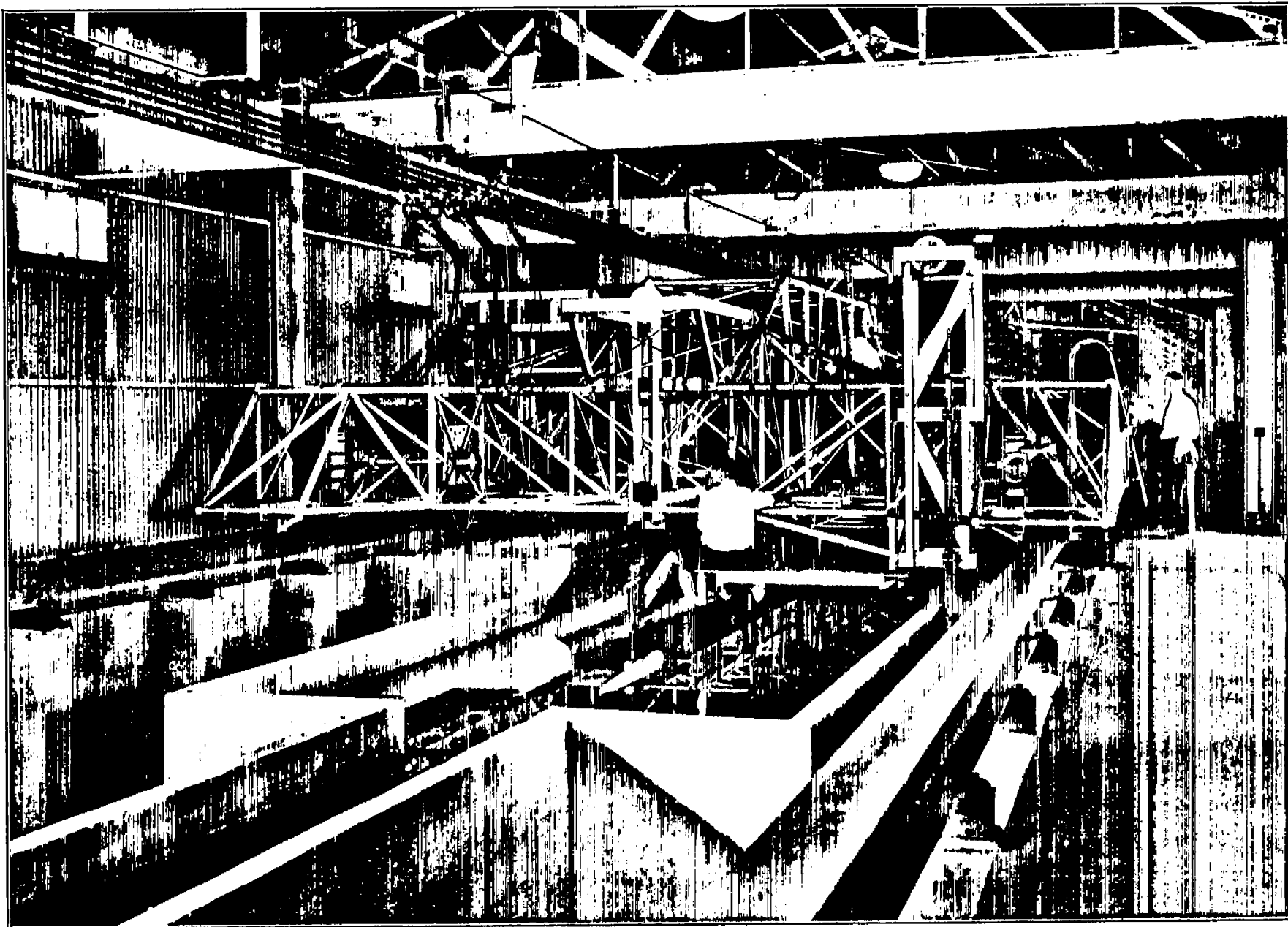


FIGURE 3.—N. A. C. A. TANK

FOR INVESTIGATION OF HYDRODYNAMIC CHARACTERISTICS OF MODEL SEAPLANE FLOATS AND HULLS. TOWING CARRIAGE WITH MODEL FLOAT IN PLACE. CARRIAGE HAS A RUN OF 2,000 FEET AT SPEEDS VARYING FROM 4 TO 58 MILES PER HOUR.

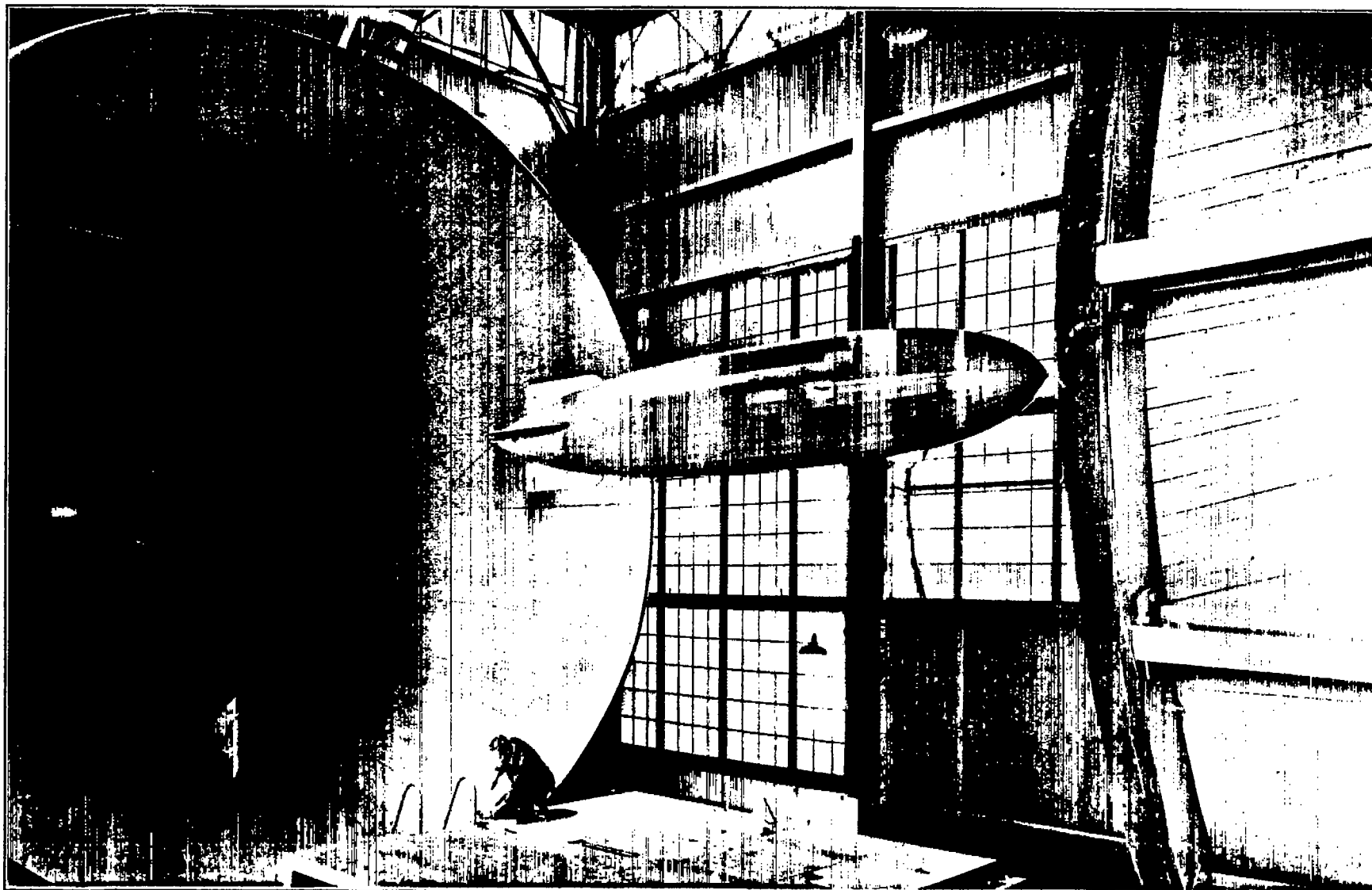


FIGURE 4.—PROPELLER RESEARCH TUNNEL

FOR INVESTIGATION OF FULL-SCALE PROPELLERS AND LARGE MODELS OF AIRPLANES AND AIRSHIPS. 20-FOOT MODEL OF U. S. S. "AKRON" UNDER INVESTIGATION TO DETERMINE LIFT, DRAG, PITCHING MOMENTS, AND PRESSURE DISTRIBUTION. THE TUNNEL HAS AN AIR STREAM 20 FEET IN DIAMETER WITH A VELOCITY OF 100 MILES PER HOUR.

PART II

GENERAL ACTIVITIES

STUDY OF AIRCRAFT ACCIDENTS

In response to the need for a standard basis for the classification and comparison of aircraft accidents, both civil and military, the National Advisory Committee for Aeronautics, in October, 1928, issued a chart for the analysis of aircraft accidents. This chart, which, together with a detailed explanation of its use, was published as Technical Report No. 308, provided for the study of the immediate causes, the underlying causes, and the results of accidents. The chart had been prepared after a thorough study of the problem by a special committee on the nomenclature, subdivision, and classification of aircraft accidents, which had been organized by the National Advisory Committee for Aeronautics at the request of the air coordination committee, consisting of the Assistant Secretaries for Aeronautics in the War, Navy, and Commerce Departments.

This chart was officially adopted by the War, Navy, and Commerce Departments for use in the study of aircraft accidents. In order to assist in the coordination of this work and to provide for the consideration of such other problems relating to aircraft accidents as might be desirable, the National Advisory Committee for Aeronautics, on completion of the work of the special committee on the nomenclature, subdivision, and classification of aircraft accidents, organized a standing committee on aircraft accidents. This standing committee has since prepared a revision of Technical Report No. 308, in which a number of the definitions in the original report were clarified and statistical information was presented showing a comparison of the types of accidents and causes of accidents in the military services on the one hand and in civil aviation on the other, together with explanations of some of the important differences noted in this comparison. The revised report was issued by the committee in 1930 as Technical Report No. 357.

The actual study and analysis of the various individual accidents and the preparation of statistical information on the problem are made by the Army Air Corps, the Bureau of Aeronautics of the Navy, and the aeronautics branch of the Department of Commerce for their respective organizations. In this study the chart issued by the National Advisory Committee for Aeronautics forms the basis. The use of

the chart in these three departments has definitely demonstrated its practical value, and has made it possible to obtain certain standard and definite information regarding each accident, to make a comparative study of accidents from the information thus obtained, and to compile statistical data of the highest importance.

By this method of analysis it has been possible to determine with reasonable accuracy the percentage of accidents due to faulty piloting and other errors of personnel, and the percentage due to matériel failures; to separate the percentage of faulty piloting into various kinds of errors of pilots, such as errors of judgment, poor technique, disobedience of orders, etc.; and to separate the matériel failures into the failures of various parts of the airplane. A similar detailed study is made of the underlying causes, such as poor reaction, inherent or temporary; lack of experience, special or general. All these causes are studied in their relation to the total number of accidents and to the number of fatal accidents. With this information at hand it is possible for the two military services and also for the Department of Commerce to take immediate action toward the elimination of those conditions, either of personnel or of matériel, which have been shown as productive of serious results in aircraft operation.

The National Advisory Committee for Aeronautics keeps in touch with this work and through the committee on aircraft accidents cooperates whenever the need arises.

During the past year, Dr. George K. Burgess, who had given most whole-hearted and effective service as chairman of the special subcommittee on the nomenclature, subdivision, and classification of aircraft accidents and as chairman of the standing committee on aircraft accidents, was relieved from the chairmanship at his own request, and Hon. Edward P. Warner was appointed to succeed him.

The present organization of the committee on aircraft accidents is as follows:

Hon. Edward P. Warner, editor of "Aviation," chairman.

Lieut. Harold Brand, United States Army, Air Corps.

George W. Lewis, National Advisory Committee for Aeronautics.

W. Fiske Marshall, aeronautics branch, Department of Commerce.

Lieut. Commander Frank D. Wagner, United States Navy, Bureau of Aeronautics.

Lieut. Frank Ward, United States Navy, Bureau of Aeronautics.

Lieut. Lyman P. Whitten, United States Army, Air Corps.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, a patents and design board was created, and it was provided that upon recommendation of the National Advisory Committee for Aeronautics the board should determine questions as to the use and value to the Government of aeronautical inventions submitted to the Government. By act of Congress approved March 3, 1927, the act of July 2, 1926, was amended in such a manner as to limit the board to the consideration of such cases as were favorably recommended to it by the National Advisory Committee for Aeronautics. This relieved the board of the burden of considering cases which were unfavorably recommended by the committee, but at the same time it made the National Advisory Committee for Aeronautics responsible for the final disapproval of the large majority of the devices submitted as applications for awards.

In order to discharge the duties devolving upon the committee under this legislation, a committee on aeronautical inventions and designs was created, the present membership of which is as follows:

Dr. D. W. Taylor, chairman.

Dr. George K. Burgess, vice chairman.

Prof. Charles F. Marvin.

J. F. Victory, secretary.

Inventions and designs submitted are considered by the director of aeronautical research. The committee on aeronautical inventions and designs considers only such inventions or designs as are presented by the director of aeronautical research or are recommended for committee consideration by a member of the National Advisory Committee. The director of aeronautical research is authorized to submit his unfavorable recommendations direct to the aeronautical patents and design board, but any favorable recommendation must be considered and made by the committee on aeronautical inventions and designs.

Under the present procedure careful consideration is given to all inventions and designs submitted. The aeronautical patents and design board and the National Advisory Committee for Aeronautics are working in harmony, and the burden of considering large numbers of inventions is placed so as to limit the demands on the time of the members of the committee on aeronautical inventions and designs and of the members of the aeronautical patents and design board

to the consideration of submissions which have received competent preliminary examination and are deemed worthy of further consideration.

The aeronautical patents and design board has been in operation five years. During the past year the National Advisory Committee for Aeronautics received about 2,050 letters relating to inventions. Approximately 800 of these represented new submissions. The majority of these cases, being addressed to the committee, were acted on by direct correspondence with the submitters. Seventy-six cases were submitted to the aeronautical patents and design board, and the committee prepared an individual report as to the merits of each particular invention or design for the action of the board.

RELATIONS WITH THE AIRCRAFT INDUSTRY

The committee cooperates closely with representatives of the aircraft industry in planning research programs which are of particular interest to commercial aeronautics. The general program of research as formulated by the committee for the cowlings and cooling of radial air-cooled engines was circulated to engineers of the industry and their comments obtained, and the result of this investigation was the development of the N. A. C. A. cowlings. During the past year a program for the study of the interference drag of combinations of engine nacelle and wing has been completed, and the preliminary results have been forwarded to the airplane manufacturers and used by them in recent designs of various types of airplanes. The committee has under way a study of the landing and take-off characteristics of airplanes, and preliminary results have been forwarded to various manufacturers for their comments and suggestions. The committee takes advantage of every opportunity to obtain the comments and suggestions of the industry in carrying out research programs.

One problem in connection with which there has been active cooperation with the industry is the study of load factors in flight due to atmospheric disturbances. A number of air transport companies have cooperated with the committee in this investigation. A special type of accelerometer was developed by the committee for this purpose, and instruments have been or are being installed by the Boeing Air Transport, American Airways, Ford Motor Co., Pan American Airways (between Brownsville, Tex., and Mexico City), and Ludington Air Line, on airplanes in regular operation. Records of special interest were obtained by the Boeing Air Transport in operation between Cheyenne, Wyo., and Oakland, Calif., and between Oakland and Seattle. An improved instrument has recently been developed by the committee which will register both applied load factors and corresponding air speeds, and this will greatly facilitate the task

of obtaining the information needed in the study of this problem.

Annual research conference.—In 1926 the National Advisory Committee for Aeronautics established the policy of holding at its laboratory at Langley Field, the Langley Memorial Aeronautical Laboratory, annual conferences with representatives of the manufacturers and operators of aircraft. The purpose of these conferences is to give to the representatives of the industry an opportunity to become acquainted with the facilities for aeronautical research at the committee's laboratory and also to afford them an opportunity to make suggestions to the committee as to aeronautical research problems of interest to the industry which in their opinion the committee is especially equipped to solve.

In accordance with this policy, the sixth annual aircraft engineering research conference was held at the committee's laboratory on May 27, 1931. The committee was represented by its officers, members of the main committee, and the members of its committee on aerodynamics, committee on materials for aircraft, and subcommittee on airships. The conference was presided over by Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics.

This year the most important features of the conference were the dedication and placing in operation of the committee's two new pieces of research equipment, the full-scale wind tunnel and the seaplane towing channel, now officially designated the N. A. C. A. Tank. These ceremonies were held immediately preceding the opening of the afternoon session of the conference. The full-scale wind tunnel was dedicated and formally placed in operation by Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics, and the N. A. C. A. Tank by Dr. David W. Taylor, vice chairman of the committee.

The dedication of the N. A. C. A. Tank was held immediately after lunch. In dedicating the tank, Doctor Taylor stated that the use of towing tanks for the study of the resistance of ships, initiated by William Froude, had become general in connection with ship design, but that ship tanks were not suitable for tests of seaplane floats and hulls on account of the low speeds to which they were limited. He referred to the need for a tank adapted to research on seaplane design, and outlined briefly the history of the N. A. C. A. Tank, stating that it had been recommended to the executive committee on January 29, 1929, by the director of aeronautical research, Mr. George W. Lewis; that estimates for its construction had been submitted to the Bureau of the Budget on February 11, 1929; and that the appropriation had been provided by Congress in a deficiency act approved March 4, 1929. Mr. Starr Truscott, the engineer in charge of the construction and operation of

the tank, described in a general way the tank, the towing carriage, and the electrical equipment. Doctor Taylor then pressed the button which gave the signal for placing the tank in operation, and the towing carriage moved through the water carrying an observer and towing a model of an *XPH-1* flying-boat hull.

The dedication of the tank was followed by the dedication of the full-scale tunnel by Doctor Ames. He referred briefly to some of the important developments in the history of the science of aerodynamics, and particularly in the history of wind tunnels, mentioning the early wind tunnels of Sir Hiram Maxim and Orville and Wilbur Wright. He then told briefly the study of the development of the full-scale wind tunnel, stating that the committee submitted to the Bureau of the Budget in 1928 a request for authority to expend \$5,000 for the design of such a tunnel; that this authority was obtained in act of Congress approved May 16, 1928; that an appropriation of not to exceed \$900,000 for the construction of the tunnel, to be available during a period of two years, was provided in act approved February 20, 1929; and that the contract for its construction was awarded on February 12, 1930. The more important details of the tunnel, including its balance and other equipment, were then described by the engineer in charge of its construction and operation, Mr. Smith J. DeFrance, after which Doctor Ames with the following comment, pressed the button by means of which the propellers were rotated and the air stream of the tunnel was set in motion:

"This committee started its work in 1915. I regard this moment as probably the most important moment in the history of the committee, because it is to set in operation a piece of apparatus which promises to give in the shortest time the most important information desired in the development of aerodynamics; an instrument which is unique in the world, and which we owe to the ingenuity of our engineers and to a Congress and a budget committee who understood our problem and were willing to cooperate with us."

At the morning session of the conference, the principal investigations under way at the laboratory, both in aerodynamics and power plants, were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained.

Among the more important aerodynamic investigations outlined were the comprehensive study in the variable-density wind tunnel of the effect of changes of shape of systematic series of airfoils; study of the effects of various locations of engine nacelle with reference to a wing; investigation in the 20-foot wind tunnel of the lift, drag, and pitching moments on a model of the airship U. S. S. *Akron*; comparison of the drag characteristics of various airships; study

of the factors affecting the behavior of an airplane in a spin; determination of the effect of wing-tip shape on the load distribution; study of the loads on the leading edge of a wing; fundamental investigation of stressed skin, or monocoque, construction; determination of tail surface loads in high-speed dives and sudden pull-ups; and investigation of lateral control and stability at low speeds and high angles of attack, including tests with a special long-travel shock-absorbing landing gear and the study of slots and flaps.

The power-plant projects described were those relating to: First, the study of superchargers for aircraft engines, which included a comparison of the performance of superchargers of the centrifugal, Roots, and vane types; second, the investigation of methods of increasing the power of aircraft engines, including a study of the effect on engine performance of increasing the carburetor pressure for various compression ratios, and the development of a 2-stroke cycle single-cylinder air-cooled engine for aircraft, using gasoline injection and spark ignition; third, the study of methods of decreasing the fire hazard in aircraft engines, in connection with which a method of reducing the temperature of long exhaust stacks had been developed, and a study had been made of fuels of higher flash point than gasoline (hydrogenated fuels); and, fourth, the study of the compression-ignition engine, which included investigation of the injection characteristics and the combustion characteristics of fuel sprays.

At the close of the session, the representatives of the industry were conducted on a tour of inspection of the committee's laboratories, and the research equipment was shown in operation.

The afternoon session was devoted to the discussion of the problems of commercial aeronautics. Prior to the conference, the committee had requested the representatives of the industry to submit suggestions in writing, and a large number were received. In addition, several such suggestions were presented and discussed at the conference. Among these were the study of the vibration characteristics of airplanes and the development of a vibration indicator; the investigation of tandem engine arrangements with reference to an airplane wing, and the study of the efficiency of propellers in tandem; the investigation of slipstream effect; the problem of the maneuverability and controllability of an airplane; the investigation of flying boats with sponsons; the study of the characteristics of forms of hull bottoms for flying boats; the cooling of air-cooled cylinders, including the study of the air flow over the cylinder head; and the investigation of the effect of propeller efficiency and pitch setting on fuel consumption.

All the suggestions for investigation presented in connection with the conference, totaling 43, including both those presented in the discussion in the afternoon session and those submitted in correspondence, have been carefully studied and classified. Those relating to aerodynamics, aircraft power plants, and aircraft structures have been considered by the appropriate subcommittee in each case. The suggestions for investigations in the N. A. C. A. Tank have not as yet been referred to a subcommittee for consideration, as the general program for the tank is still in formulation. Most of the aerodynamic, power plant, and materials problems were already a part of the committee's research program, and in a number of other cases the program for a certain investigation has been modified to include the particular phase of the problem suggested.

COOPERATION OF ARMY AND NAVY

Through the personal contact of the heads of the Army Air Corps and of the Bureau of Aeronautics of the Navy serving as members of the National Advisory Committee for Aeronautics and of their chief subordinates acting as members of the subcommittees, there is first-hand discussion of the technical problems of these organizations, and this has served to promote the coordination of research and experimental work in both aerodynamics and power plants.

Through this contact also the problems of these organizations are brought to the attention of the committee, and much of the fundamental research of the committee has resulted from requests received from the Army and Navy for the study of particular problems. The success attained in the study of these problems is to a large extent dependent upon the cooperation of the Army and Navy in placing at the committee's disposal airplanes and engines required for research purposes. The committee desires to give special recognition to this splendid spirit of cooperation, without which many of the investigations requested could not have been conducted effectively. The committee wishes in particular to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and by the naval authorities at the Hampton Roads Naval Air Station.

INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY

As a rule research programs covering fundamental problems demanding solution are prepared by the technical subcommittees and recommended to the executive committee for approval. These programs supply the problems for investigation by the Langley Memorial Aeronautical Laboratory. When, however,

the Army Air Corps, the Bureau of Aeronautics of the Navy, or the aeronautics branch of the Department of Commerce desires special investigations to be undertaken by the committee, such investigations, upon approval by the executive committee, are added to the current research programs.

The investigations thus under conduct by the committee during the past year for the Army and the Navy may be outlined as follows:

FOR THE AIR CORPS OF THE ARMY

Investigation of pressure distribution and accelerations on pursuit-type airplane.

Acceleration readings on the *PW-9* airplane.

Investigation of pressure distribution on observation-type airplane.

Investigation of tail surface loads in maneuvers.

Determination of coefficients of contraction for oleo landing gear orifices.

Investigation of slipstream velocities near airplane tail surfaces.

Determination of standard design characteristics for certain airfoils.

Pressure distribution on ring cowlings.

Wind-tunnel investigation of biplane cellules.

Study of ice formation.

Investigation of velocity distribution in plane of propeller disk.

Investigation of cowling for protection of gunners and pilots from air currents.

Determination of moment coefficients and hinge moment coefficients for different tail surfaces.

Determination of aileron hinge moments versus rolling moments for various types of ailerons and wings.

Investigation of wing flutter.

Investigation of the flat spin.

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

Investigation of design of floats for racing seaplanes.

Study of loads on wings of military-type airplanes.

Investigation of aerodynamic loads on U. S. S. *Akron*.

Study of water-pressure distribution on seaplane floats and hulls.

Development of cowling combining cooling, accessibility, and low drag, for radial air-cooled engines installed in nacelle.

Investigation of lift, stability, and control characteristics of *XSL-1* airplane.

Comparative tests of rubber and oleo type landing gears.

Study of design factors for metal propellers.

Investigation of methods of improving wing characteristics by control of the "boundary layer."

Ice formation on aircraft.

Investigation of comparative aerodynamic resistance of riveted and bolted construction.

Investigation of effect of sags in wing surface.

Investigation of windshields and fairings for protection from air currents.

Investigation of flight-path characteristics.

Investigation of autorotation.

Development of solid-injection type of aeronautical engine.

Study of effect of different degrees of supercharging with several compression ratios.

COOPERATION WITH STATE DEPARTMENT ABROAD

The committee cooperates with the Department of State by making available, as the occasion arises, the services of its technical assistant in Europe, Mr. John J. Ide, for attendance as an unofficial observer or technical adviser on behalf of the United States at various international air conferences abroad. In response to invitation from the League of Nations and at the request of the State Department, Mr. Ide served as a member of a special committee of experts which met at Geneva April 20 to 24, 1931, for the purpose of establishing a standard of horsepower measurement for aircraft engines, for use at the general disarmament conference to be held by the League of Nations in 1932. This committee of experts recommended a formula for horsepower measurement based on the volume of the engine cylinders and the weight of the engine.

On designation of the Department of State, Mr. Ide served as a delegate on the part of the United States to the first international congress on aerial safety held at Paris in December, 1930.

In response to inquiry from the State Department, the National Advisory Committee for Aeronautics, by resolution adopted at its semiannual meeting held on April 23, 1931, expressed the opinion that the time has arrived for the adoption of a definite policy with respect to the degree of participation by delegates of the United States in future international air congresses.

REVISION OF NOMENCLATURE FOR AERONAUTICS

The National Advisory Committee for Aeronautics has recently organized a special conference on aeronautical nomenclature, for the revision of its standard nomenclature for aeronautics, which was published in 1926 as Technical Report No. 240. The nomenclature for aeronautics is adopted by the committee for the purpose of securing greater uniformity and accuracy in the use of terms relating to aero-

nautics in official documents of the Government and, as far as possible, in technical and other commercial publications. Revisions in the nomenclature are made from time to time as the occasion arises, to conform with changes in the general use of aeronautical terms.

Before proceeding with the organization of the special conference, the committee requested suggestions from a large number of organizations and individuals interested as to modifications in the present authorized nomenclature. These suggestions now are being carefully considered by the special conference.

The nomenclature includes within its scope terms relating to types of aircraft, to lighter-than-air craft, to airplanes, to aircraft materials and structures, to airports and landing fields, to aerodynamics, to propellers, to instruments and auxiliary apparatus, and to engines. Suggestions as to terms dealing with these various subjects are being requested from individuals particularly interested, and all the suggestions received will be given careful consideration by the conference.

The organization of the special conference on aeronautical nomenclature is as follows:

Dr. Joseph S. Ames, chairman.

Representing the National Advisory Committee for Aeronautics—

Charles H. Helms.

Carlton Kemper.

George W. Lewis.

H. J. E. Reid.

Hon. Edward P. Warner.

Representing the Army Air Corps—

Capt. Karl S. Axtater, United States Army.

Capt. Albert C. Foulk, United States Army.

Lieut. A. F. Hegenberger, United States Army.

Maj. C. W. Howard, United States Army.

Capt. E. R. Page, United States Army.

Representing the Bureau of Aeronautics of the Navy—

Lieut. Commander W. S. Diehl (C. C.), United States Navy.

Commander Garland Fulton (C. C.), United States Navy.

Lieut. Commander R. D. MacCart (C. C.), United States Navy.

Commander C. A. Pownall, United States Navy.

Commander R. D. Weyerbacher (C. C.), United States Navy.

Representing the Bureau of Standards—

Dr. L. J. Briggs.

Dr. W. G. Brombacher.

Dr. H. C. Dickinson.

Dr. H. L. Dryden.

Representing the aeronautics branch, Department of Commerce—

Col. H. H. Blee.

Richard C. Gazley.

Capt. F. C. Hingsburg.

PART III

REPORTS OF TECHNICAL COMMITTEES

REPORT OF COMMITTEE ON AERODYNAMICS

ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. David W. Taylor, chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lieut. Commander W. S. Diehl (Construction Corps), United States Navy.
Dr. H. L. Dryden, Bureau of Standards.
Capt. Albert C. Foulk, United States Army, matériel division, Air Corps, Wright Field.
Richard C. Gazley, aeronautics branch, Department of Commerce.
Maj. C. W. Howard, United States Army, matériel division, Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Prof. Charles F. Marvin, Weather Bureau.
Hon. Edward P. Warner, editor of "Aviation."
Commander W. W. Webster (C. C.), United States Navy.
Dr. A. F. Zahm, division of aeronautics, Library of Congress.

FUNCTIONS

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.

2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.

3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments in progress or proposed.

4. To direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.

5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on aerodynamics, by reason of the representation of the various organizations interested

in aeronautics, is in close contact with all aerodynamical work being carried out in the United States. The current work of each organization is therefore made known to all, duplication of effort being thus prevented. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduct of aerodynamic research. The committee keeps the research workers in this country supplied with information of European progress in aerodynamics by means of a foreign representative, who is in close touch with aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field and of a number of special investigations conducted at the Bureau of Standards. The aerodynamical investigations undertaken at the Washington Navy Yard, the matériel division of the Army Air Corps at Wright Field, and the Bureau of Standards are reported to the committee on aerodynamics.

During the past year the subcommittee on aeronautical research in universities, which had been established in 1928 as a subcommittee of the committee on aerodynamics, was discharged. This subcommittee was originally organized to aid in the establishment of contact and cooperation between representatives of the various educational institutions engaged in the teaching of aeronautical engineering, which had been initiated by the Daniel Guggenheim Fund for the Promotion of Aeronautics. It was the opinion of the committee that such contact and cooperation had been definitely established and was being continued by a national conference on aeronautical education held annually under the joint auspices of the educational committee of the Aeronautical Chamber of Commerce and the Daniel Guggenheim Fund committee on elementary and secondary aeronautical education.

SUBCOMMITTEE ON AIRSHIPS

In order that the committee on aerodynamics may be kept in close touch with the latest developments in the field of airship design and construction and that

research on lighter-than-air craft may be fostered and encouraged, a subcommittee on airships has been organized under the committee on aerodynamics, the membership of which is as follows:

Hon. Edward P. Warner, editor of "Aviation," chairman.

Starr Truscott, National Advisory Committee for Aeronautics, vice chairman.

Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.

Capt. Karl S. Axtater, United States Army, matériel division, Air Corps, Wright Field.

Commander Garland Fulton (C. C.), United States Navy.

George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Ralph H. Upson, Dearborn, Mich.

The subcommittee on airships has kept in close touch during the past year with the investigations conducted at the Langley Memorial Aeronautical Laboratory on models of the U. S. S. *Akron*. At a meeting of the subcommittee held on January 10, 1931, preliminary results obtained in the variable-density tunnel on a 1/200-scale model of the airship were presented and discussed, and details of the program of further tests, both in this tunnel and on a larger model in the propeller-research tunnel, were decided upon and action taken to expedite these tests in view of the importance of the results in connection with the design of the full-size airship. At this meeting there was also discussion of tests in the variable-density tunnel on a model of a proposed large metal-clad airship and of the problem of the ground handling of airships.

At a special meeting of the subcommittee on airships held on May 27 at the Langley Memorial Aeronautical Laboratory in connection with the sixth annual aircraft engineering research conference, results were presented from the tests in the propeller research tunnel on a 1/40-scale model of the *Akron*, including hinge moments and forces on the model for various angles of rudder setting and various angles of attack, the rudder being equipped with balancing vanes. Details of further tests to obtain the information most needed in connection with the completion of the full-size airship were agreed upon.

The subcommittee on airships has also cooperated with the subcommittee on meteorological problems of the committee on problems of air navigation in connection with the study of wind gustiness. A joint meeting of the two subcommittees for the discussion of this problem was held on January 10, 1931.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The problems confronting aeronautics may be divided into two general categories—those affecting

safety and those affecting efficiency. As in previous years, the aerodynamic work of the laboratory has been devoted to the solution of problems falling under both these heads; investigations of stability and control, landing, spinning, structural loading, and the prevention of ice formation are examples of those affecting safety, while investigations of aerodynamic interference and drag, maneuverability, propellers, and airfoils are examples of those made in the interest of greater efficiency. As in previous years, there have been additions to the testing equipment of the laboratory.

Stability and control.—From the standpoint of the aerodynamics of the airplane, it appears that the most promising immediate line of attack in the interest of safety is to find means of decreasing landing and take-off speeds and of providing adequate stability and control at the attitudes corresponding to these speeds. Because of their known ability to increase the lift coefficient, slots and flaps constitute one method of accomplishing this object.

As a part of its general research on safety the committee is therefore undertaking the investigation in flight of aerodynamic performance and of the landing, take-off, stability, maneuverability, and control characteristics of an airplane equipped with slots (extending over the entire span of the wings) and flaps (extending only to the ailerons), so that the influence of these devices can be appraised not only with regard to safety but with regard to performance in general. One phase of the investigation, the effect of the slots and flaps on the lift and drag characteristics of the airplane, has been completed and a report has been prepared for publication. The results show that with this particular airplane the slots used alone increase the maximum lift coefficient 54 per cent; the flaps alone increase it 38 per cent; and the slots and flaps in combination give a total increase in lift coefficient of 94 per cent. The slots and flaps in combination decrease the landing speed from 60 to 43 miles per hour; increase the speed range of the airplane 40 per cent; and increase the glide angle at landing speed 4.2°.

The autogiro offers another very promising method of increasing the safety of flight. The committee has purchased an autogiro of the latest type and is just starting an extensive research, including both flight tests and tests in the full-scale wind tunnel, to study the aerodynamic characteristics of this type of aircraft.

It appears that the spinning problem, as it applies to commercial airplanes, could be best solved by preventing the spin entirely. To this end a flight investigation was continued in which the elevator control was limited to prevent the stall and the effect on the performance determined. This was done with seven different designs of airplanes, and with the elevator

travel limited to the point where the airplanes could not be made to spin without the aid of power. The lateral control and aileron effectiveness were in every case satisfactory up to the highest angles of attack which could be obtained in a glide, although this was not true in any case without the limited control. All ordinary flight maneuvers could be performed with the elevator displacement limited, but usually there was not sufficient control to get the tail down for a normal three-point landing. On this account a different form of landing called a "glide landing" was investigated. This type was made by gliding straight to the ground with the full but limited amount of tail-displacing longitudinal control in use. Since the vertical velocities in these glides range from 12 to 24 feet per second with different airplanes, it was evident that a landing gear having a long stroke and excellent shock-absorbing qualities would be required. One of the airplanes, the Verville AT, was fitted with long-travel shock-absorber struts and actual landing tests were made in which the accelerations upon contact with the ground were measured. The glide landings with the control stick full back to the limited position were satisfactory, the landing runs, as well as the air distances required to clear a 50-foot obstruction and alight on the ground, being substantially shorter than with the shortest present-day conventional landing. It was concluded that most conventional airplanes, if their elevator control and landing gear were modified in this manner, could be landed with less skill in a small space and with no possibility of falling into a spin without the aid of power. One question that arises in connection with this type of landing is the effect of rough air conditions on the vertical velocity at landing. It is possible that down currents in the atmosphere near the ground will produce greater vertical velocities than those experienced in the tests at higher altitudes. The investigation is being continued by providing the airplane with a longer-travel landing gear and properly strengthened primary structure in preparation for an extensive series of actual landings in air of various degrees of roughness to determine the effect of the air conditions near the ground on the vertical velocities.

Another flight investigation has been completed in which the longitudinal stability of a small high-wing monoplane was determined. It is expected to use this airplane to try out in flight any control devices that wind-tunnel tests now in progress indicate to have possibilities of improving stability and control, particularly at low speeds. In the investigation conducted, the important resistance and rotary derivatives and the damping coefficients were measured in two conditions of flight, power on and power off. A paper is being prepared giving these results compared to values of the same quantities predicted by theory.

Wind-tunnel pressure-distribution tests have been made on a series of models to study the effect on stability in roll of the distribution of the lift along the span. Three methods of changing the distribution were employed—twist or washout, sweepback, and variation in profile to a thin symmetrical section at the tip. The results, which have been published, showed that washout, whether obtained by merely twisting the wing or by varying the airfoil section along the span, appreciably reduced the maximum instability in rolling, but that sweepback or sweepforward had no clearly defined effect.

Further pressure-distribution tests of the same nature were made on biplanes having various amounts of gap, stagger, decalage, and overhang. These tests showed that unstable rolling moments due to a low rate of roll are usually decreased by a gap-chord ratio of less than one, by positive stagger alone, or by positive stagger and negative decalage. The combination of positive stagger and negative decalage gives the best lateral and also the best longitudinal stability of any wing arrangement investigated. A technical report covering this work is in process of publication.

Aerodynamic force tests on a slotted Clark Y wing were conducted in the vertical wind tunnel to determine the best position for a given auxiliary airfoil with respect to the main wing. A systematic series of 100 changes in location of the auxiliary airfoil was made to cover all the probable useful ranges. The results are being prepared for publication. An increase of 41.5 per cent in the maximum lift coefficient above that of the plain wing was obtained with the best position. Following this investigation another was undertaken to develop a low-drag fixed slot for an airplane wing that would avoid the complications and maintenance difficulties of the present movable-type Handley Page slots. The best combination of wing and fixed slot that was developed had a maximum lift coefficient which was 34.6 per cent higher than that of the plain wing, and the ratio of maximum lift to minimum drag was but slightly lower than for the plain wing. It is estimated that if these fixed slots were used only at the tips of the wings for the purpose of improving the lateral stability at high angles of attack, the total drag of an airplane would be increased very slightly. A technical report on this work is in process of publication.

A rather extended investigation has been started in which it is intended to compare the relative merits of all ordinary and some special forms of ailerons and other lateral-control devices in regard to their effect on lateral controllability and lateral stability at high angles of attack, and also their effect on airplane performance. The comparisons are based on

wind-tunnel test data, all the control devices being fitted to model wings having the same span, area, and airfoil section and being subjected to the same series of force and rotation tests. These tests, which are being made in the 7 by 10 foot tunnel, have been completed for ordinary ailerons of three different sizes, all mounted in the usual position at the trailing edge of the wing, and with five different types of movement, including two differential systems, an arrangement permitting upward movement only, and one in which the ailerons were arranged to float. The results showed that, although the ailerons with the commonly used motions gave very unsatisfactory control above the stall, satisfactory control was obtained by short, wide ailerons with upward deflection only, and satisfactory control was closely approached by the same ailerons with an extreme differential motion. The floating ailerons had the smallest yawing moments and gave a decided improvement in lateral stability. Tests have also been completed on slotted ailerons and Frise ailerons. None of these gave as good control above the stall as the plain ailerons, although the Frise ailerons gave somewhat better yawing moments. Several technical reports covering this work are in preparation.

Spinning.—With military airplanes the spin is considered a necessary maneuver. Both flight and wind-tunnel work are being carried on by the committee to add to the present knowledge in regard to the spin and to make it possible to design airplanes that will spin satisfactorily and recover quickly and surely. A report has been published during the year describing the methods used in flight for the determination of the flight path, the motion, the attitudes, the forces and couples of a fully developed spin. The flight investigation of spinning has been in progress throughout this year on one airplane, and the phase which deals with the effect of mass distribution on the spin characteristics has been completed. In this work the effect of changes of mass distribution along the three axes of the airplane has been determined. With this airplane, as was the case with a previous one which was tested in flight, it was not possible to produce an uncontrollable spin with the changes possible either in mass distribution or balance. While the results have not been completely analyzed as yet, it appears that with the data now available the effect of the mass distribution on the character of the spin of any airplane can be calculated if a certain few of the aerodynamic characteristics of the spin are known. This spin investigation is to be carried further on this same airplane to find the effect of changes in the control surfaces and wing section and the geometric proportions of the airplane on the character of the spin and the entry and recovery from same.

During the year there became available the results of wind-tunnel tests at high angles of attack, of a model of an airplane which had been previously flight-tested in spin. A study is now in progress to determine the practicability of computing the full-scale spin characteristics from the results of standard model tests at high angles of attack, and of possibly determining the correction factors necessary to make such computed characteristics applicable to full scale.

The moments and ellipsoids of inertia of all airplanes used in flight investigations have been measured as in the past. Two reports have been published, one describing the method of making these measurements, and another giving the moments of inertia of 12 different airplanes.

Structural loading.—Recent structural failures on several military and commercial airplanes, both in this country and abroad, have focused the attention of designers more than ever on questions of the external loads acting on airplanes in flight. This subject has been studied actively for several years by the flight research section and still remains a major problem. A report on the magnitude and distribution of the aerodynamic and inertia loads on the wings and tail surfaces of a pursuit-type airplane in a wide variety of maneuvers has been published. A report on the magnitude and distribution of aerodynamic loads over the fuselage of the same airplane has also been published. These reports have served principally to call attention to important phenomena affecting structural loads, which have been given no attention in the past, and they have therefore contributed greatly to our insight into the broad problem of structural loading. In two instances they have, in conjunction with other data previously and since obtained, enabled specific design rules to be formulated. One of these, a formula for the determination of design tail loads, has been incorporated in the latest Army design handbook.

A report is now in process of publication which gives a method of calculating the design load for the leading-edge portion of the wing. This method is based on theory and pressure data, all of which are products of the committee's laboratory.

The investigation of the pressure distribution over an airplane wing fitted with a series of wing tips of different shapes has been continued, and tests on seven tips have been completed. The results for five of these tips have already been published, and a report on the other two that have been tested is now in preparation. The objects of this investigation are to develop a tip of such shape that the center-of-pressure locus will be a straight line in the critical loading conditions and to formulate laws of load distribution over wing tips of any shape. Work on this investigation thus far has been centered mainly on the accumula-

tion of data, but sufficient study has been given the results to indicate that the object will be attained.

A number of flight investigations have been made, and several are now in progress, to determine the proper load factors or total loads to use in design. These investigations cover a wide field, including measurements of acceleration on transport airplanes flying commercial routes, as well as measurements on military and naval aircraft in special tactical maneuvers. A report has been published giving some of the results obtained on commercial airplanes in bumpy air, and several confidential reports on load factors for military and naval airplanes have been issued to the services. It has been concluded that, while the load factor can be determined by rational means when the conditions to which the airplane is to be subjected are known, so little is known about these conditions that extensive statistical information will be required before the load-factor problem can be satisfactorily solved. In this connection, data on the accelerations encountered by transport airplanes flying in rough air have been accumulated during the year on several airplane lines throughout the country by means of the special accelerometers developed for this work. The value of these records has been limited by the lack of full information on the conditions of the flight, particularly the air speed when encountering rough air, which is required to interpret the records properly, but there are indications that the importance of this work is being more appreciated by operating companies and that more complete information may be expected in the future.

To facilitate obtaining the information required, a special instrument is now being developed that will register the applied load factors and corresponding air speeds over an extended period of operation for any airplane. By distributing such instruments judiciously on both commercial and service airplanes, it is expected that enough information will be obtained to solve the load-factor problem in a satisfactory way.

Prevention of ice formation on airplanes.—Under certain weather conditions a heavy coating of ice may form on the wings of airplanes, with the result that the aerodynamic properties of the lifting surfaces are so altered that a forced landing becomes necessary. The committee has undertaken an investigation of the practicability of employing heat as a means of preventing such ice formation on wings. A study of the heat transmission from an airfoil, supplemented by ice-prevention experiments both in the refrigerated wind tunnel and in flight, demonstrated that it is necessary to heat only the front portion of the wing surface to effect complete prevention, and that the quantity of heat needed is small. A vapor system was found to offer the most desirable solution, the heat

being taken from the exhaust gases. Flight tests proved that this method offers a solution with practical possibilities.

Another investigation was carried out in the refrigerated wind tunnel in response to inquiries regarding the construction of gasoline-tank vents that would not freeze up during flight under ice-forming conditions. Tests were made on a variety of vent forms arranged in a number of different orientations relative to the air stream. Both the size of the tube and its orientating the need for more systematic tests, particularly arrangements were recommended as being immune to blocking by ice.

Aerodynamic interference and drag.—It is believed that the greatest opportunity for increasing the speed and efficiency of aircraft lies in reducing drag and unfavorable interference effects. In the past, the National Advisory Committee for Aeronautics has conducted several interference investigations, which have dealt with specific practical problems with a view to arriving at solutions that could be made immediately available. Such investigations have usually been made in compliance with specific requests from the Army, the Navy, or the aircraft industry. Appreciating the need for more systematic tests, particularly at Reynolds Numbers corresponding to full scale, the committee has begun several investigations along this line, which have been in progress throughout the year in the variable-density wind tunnel and the propeller research tunnel.

In the variable-density wind tunnel, the drag of various simple combinations of basic forms is being measured, two parts of the program having been completed. The first part dealt with effects of small protuberances from the surface of a streamline body of revolution. The interference for such a combination may be compared with the interference between airship hulls and protuberances, such as radiators or cars. The additional drag due to a small rectangular plate protruding normally from the surface to a distance of about one-thirtieth of the body diameter was measured over a wide range of values of the Reynolds Number. The measurements were repeated with the protuberances placed successively at different positions along the surface of the body. At the highest value of the Reynolds Number, the calculated drag of the plate alone was 10.5 per cent of the drag of the body alone. The actual increased drag varied from 10.5 per cent when the protuberance was placed near the bow to 5.7 per cent when the protuberance was near the stern. Additional tests made with streamline protuberances instead of the flat plate indicated that at the highest value of the Reynolds Number the interference effects from such a combination are very small.

The second combination to be investigated was that of an airfoil with a flat plate inserted at the midspan position parallel with the wind. This combination may be compared with a wing intersecting a flat-sided fuselage or with a strut intersecting a wing. The interference effects were determined from tests of the airfoil and plate separately and in combination. Tests were also made with several sizes of fillets placed at the intersection between the plate and the airfoil surfaces. The results indicated that the fillets had a small favorable effect on the interference, but that the interference effects arising from such a combination of airfoil and plate are very small.

The third investigation, which is now being undertaken, deals with the interference of small protuberances from an airfoil surface. First, the interference effects of small rectangular protuberances extending across the entire span of the airfoil will be measured with the protuberance placed successively at different positions along the surface. Later, the effects of protuberances of the type that fair into the surface will be measured, and, finally, protuberances which extend only over a part of the span will be investigated, with a view to studying the so-called induced-interference effects resulting from a modification of the lift distribution across the span.

The research on the relative merits of various wing-and-nacelle combinations has been carried on practically continuously during the past year in the propeller research tunnel. As a result several parts of the investigation have been brought to a conclusion and reports have been completed, or are in preparation, covering the work accomplished. Tests with two monoplane wings with a tractor propeller and nacelles with various cowlings have been completed. A report giving the results obtained with a thick monoplane wing and a completely cowled nacelle has been completed; the results indicate that a nacelle located about 25 per cent of the chord of the wing directly ahead of the leading edge gives the best over-all efficiency. A report giving the results obtained with various cowlings on the nacelle in several positions with respect to the same wing is now being prepared, as is also a report on the drags of nacelles alone, which were measured during the progress of the tests.

The question of the effect of locked or idling propellers on the lift of wings has been of some interest to airplane designers. The fast landings of several airplanes when the engine was stopped has been attributed to the effect of the stopped propeller on the lift of the wing. A large number of tests were made with the propeller locked and also with the propeller idling, with various nacelle-wing combinations and with various cowlings. The results of these tests have been prepared in the form of a report and show that

the propeller has practically no effect on the lift under the conditions named. It was noted, however, that when an uncowled radial engine was placed directly in front of the wing a large loss of lift resulted.

Airships.—At the request of the Bureau of Aeronautics of the Navy Department a one-fortieth-scale model of the new airship, the U. S. S. *Akron*, has been tested in the propeller research tunnel. In the tests the usual lift, drag, and pitching moments were determined, and in addition a special balance was installed to measure the forces and moments on the elevator hinge. Also, pressures were measured at more than 400 points on the hull and at more than 300 points on the fins. Certain special tests were also made to determine the effect of a new design of balancing control surface which had been proposed for the airship. By means of a very small Pitot tube the velocity close to the surface of the model was explored at nine stations along the axis of the ship. The impact pressure ahead of the airship and in the rear of the model was also measured. As a result of all these measurements the pressure drag and frictional drag of the model have been computed and checked with the measured values. A preliminary report covering the force tests has been submitted to the Navy Department, and the report on the pressure-distribution tests is now in preparation.

In conjunction with the Navy Department and the Goodyear-Zeppelin Corporation, a series of flight tests has just been completed on the U. S. S. *Akron*. These tests consisted of speed and turning trials, deceleration tests, and pressure-distribution measurements on part of the hull and one complete tail surface and portions of two others, in maneuvers and in rough air. It may be mentioned that the flight tests confirmed the results of the wind-tunnel tests with reference to the effectiveness of the controls.

Maneuverability.—The collection of quantitative data on the maneuverability of military airplanes, which is expected to result in definite criteria for maneuverability and the factors affecting it, has been continued. Two reports giving the measurements obtained in all types of maneuvers of two fighter airplanes have been published. Another report has been made to the Navy Department on the results of an investigation in which dives and pull-outs from dives were performed on three different Navy fighter airplanes, each airplane being flown by three different Navy pilots in the normal manner employed in diving bombing maneuvers. Another flight investigation of this same type on a Navy observation airplane has been completed and reported to the Navy Department.

In all the dive tests the flight path throughout the dive and recovery has been measured; the empirical relation between altitude lost in recovering from a

dive, the maximum acceleration encountered, and the air speed have been more accurately established and have been extended to include not only vertical dives but dives at any angle.

Propellers.—The propeller work of the laboratory during the past year has been incidental to the wing-nacelle tests in progress in the propeller research tunnel and has consisted of numerous tests of the same propeller with various nacelle locations. A number of reports have been prepared, however, covering more detailed analyses of the results of an investigation carried out during 1929, which made possible an extensive study of propeller forms and characteristics. Reports have been published giving the results of tests of propellers up to tip speeds of 1,350 feet per second, which show a large loss of efficiency beginning at about 1,000 feet per second. Another report gives a comparison of similar propellers with Clark Y and R. A. F.-6 propeller sections. The Clark Y section is shown to be no better than the R. A. F.-6 section, except at very low pitches, and there only at maximum efficiency. For the climb and take-off condition the R. A. F.-6 propeller section is decidedly superior. Another report has been prepared giving the results of tests on the effect of yaw and pitch on the propeller characteristics. An angle of pitch of 10° had small effect on the propeller characteristics, the propeller being in the nose of a fuselage. A greater drop in efficiency with increase in angle of the propeller axis to the air stream was found with a combination of nacelle and wing.

During the tests of propellers at high tip speeds above mentioned, the velocity and direction of the air flow in the rear of the propellers were measured. From these data the thrust and torque distribution along the blades of the propellers has been computed and shows clearly what part of the blades is most affected by the increase of tip speed. It is also proposed to compute from the data obtained a series of airfoil characteristics that can be used in propeller design in cases where the chart system proposed before can not be used. Reports giving the results of these computations are now in preparation.

Airfoils.—Although wind-tunnel test data are already available covering a wide variety of airfoil shapes, the data are of little comparative value because the tests were made under different conditions and at different dynamic scales at various laboratories, and, furthermore, the results can not be expected to apply to full-scale airplane wings. The design of an efficient airplane entails the careful balancing of many conflicting requirements. This statement is particularly true of the choice of the wing. The airfoil section should have a very low drag over the operating range of lift coefficients, a high maxi-

mum lift, a small center-of-pressure movement, and for structural reasons should be thick enough to provide room for an efficient structure inside. Before the requirements which are usually conflicting can be balanced, the relations between them must be known. For example, a designer wishing to investigate the possibility of lightening a wing structure could calculate the weight-saving resulting from the substitution of a thicker airfoil section, but unless he knew how the change would affect the aerodynamic properties of the wing, he could not know whether or not the change would be desirable.

The object of an investigation now being carried out in the variable-density wind tunnel is to obtain the characteristics, at large values of the Reynolds Number, of a wide variety of related airfoils. Not only do the results of such an investigation greatly facilitate the choice of the most satisfactory airfoil for a given application but, because the results may be correlated to indicate the trends of the aerodynamic characteristics with changes of shape, they also may point the way toward the development of new shapes having better characteristics.

In the development of the airfoils for the investigation, the sections were considered as made up of certain profile thickness forms disposed about certain mean camber lines. The major shape variables then were two, the thickness form and the mean camber-line form. The thickness is of particular importance from a structural standpoint. On the other hand, the form of the mean camber line determines almost independently of thickness some of the most important aerodynamic properties of the airfoil; e. g., the pitching moment characteristics and the angle of zero lift. A preliminary investigation showed that well-known airfoils of a certain class, including the Göttingen 398 and the Clark Y, which have proved to be efficient, are nearly alike when their mean camber is removed and they are reduced to the same thickness. A similar basic thickness variation was therefore chosen for the related airfoils, but related airfoils having maximum thickness-to-chord ratios varying between 0.06 and 0.21 were obtained by scaling, up or down, all of the ordinates of the basic thickness form. The shapes of the mean lines about which the thickness forms were disposed to produce the cambered airfoils were varied by changing the camber and the distance from the leading edge to the positions of maximum camber. In this way a large variety of related airfoils were obtained.

The tests of these airfoils are now in progress in the variable-density wind tunnel, and the results are being made available in the form of technical notes as the tests are completed. Information as to the characteristics of 40 of the related airfoils is now

available in published form. Some of these have characteristics superior to the best commonly used airfoils.

In addition to the main investigation, a secondary investigation of the effect of the nose shape has been carried out. Three of the symmetrical family airfoils, having maximum thickness-to-chord ratios of 0.06, 0.12, and 0.18, were modified to produce sections of the same maximum thickness, but in each case sections having a sharper and a blunter leading edge. The results of this investigation have been published.

In addition to the investigation of the characteristics of related airfoils, many commonly used airfoils have been tested in the variable-density wind tunnel. At the request of the Army and the Navy, the characteristics of additional commonly used airfoils are being determined, and to provide data for the formulation of rational loading rules for the dive and the inverted-flight conditions several of these airfoils are being investigated throughout the range of negative angle of attack to beyond the negative maximum lift. A preliminary report presenting a portion of these results has been prepared.

A short series of tests was made in the variable-density wind tunnel to investigate the possibility of controlling the boundary layer on the upper surface of an airfoil, without employing supplementary equipment, by use of the low pressure existing near the leading edge. The low pressure was used to induce flow through slots in the upper surface of the wing. The tests showed that the angle of attack for maximum lift could be increased at the expense of a reduced maximum lift coefficient and an increased drag coefficient.

Theoretical aerodynamics.—The various types of airfoils in general use exhibit quite different properties. The determination of the characteristics of the several forms has been the object of a large number of extensive tests by many institutions. Without an understanding of the theory of air flow around airfoils, it is quite difficult to interpret the results of experimental work intelligently or to make other than random improvements at the expense of much useless testing. The laboratory has, to meet this need, carried on a number of theoretical investigations.

A simple and exact method of calculating the lift distribution on thin wing sections has been developed. The essential feature of the new theory is the introduction of an "ideal angle of attack"; i. e., that angle for which the lift at the leading edge is zero. It is shown that the lift of a wing section may be considered to consist of a "basic distribution," which is the lift distribution at the ideal angle of attack and is characteristic of the section, and of an additional distribution that is identical for all thin sections. The poor aerodynamic qualities of thin wing sections are

shown to be due to the fact that the additional lift in potential flow becomes infinite at the leading edge. The location and magnitude of the maximum lift intensity were determined. Comparison with pressure-distribution measurements obtained in the variable-density wind tunnel gave a satisfactory confirmation of the validity of the theory.

A second investigation presents for the first time a solution of the problem of the theoretical potential flow around bodies of arbitrary form, which gives the exact velocity of the two-dimensional flow for any point of the surface and for any orientation, by an expression containing a number of parameters which are functions of the form only, and which may be evaluated with any desired accuracy by convenient graphical methods. The method is particularly simple and convenient for bodies of streamline form. This theory of actual airfoils has been brought into a much simpler form than has hitherto been the case with the theory of thin airfoils, in which certain approximations have restricted its applications to small cambers only. The results have been applied to typical airfoils and compared with experimental data.

A further theoretical study of the effect of the boundaries of an air stream of finite extent on the flow past an airfoil showed that it is possible to devise three distinctly new types of wind tunnels which are superior to the conventional types as regards tunnel-wall interference. Formulas were deduced for the interference in each case, and the correction, applicable to small airfoils placed in the center of the section, is given in terms of the width-to-height ratio of the various tunnels. It is, in fact, possible to design these types of tunnels having zero wall interference. The properties of these tunnels have been investigated. Attention has also been called to the fact that instability of the flow may prevent the predictability of the interference effect in certain types of open-throat tunnels.

Changes in equipment.—The spinning balance for the 5-foot vertical tunnel has been designed and the construction is well advanced. Pending the completion of this balance the tunnel is being operated with a temporary balance measuring lift, drag, and rolling moment.

The 7 by 10 foot tunnel has been completed and has been in satisfactory operation for several months. It is provided with a novel balance with which either 6-component force tests or autorotation tests can be made, and the results read off directly in coefficient form. This feature eliminates the necessity of computing the various coefficients and consequently saves an appreciable amount of time. A technical report describing the tunnel and the balance is in process of publication.

During the past few months the outer walls of the propeller research tunnel, which were of wood siding, have been replaced with corrugated asbestos siding, and the inner walls of the cones and the test chamber have been partially lined with sheet metal. These changes in the tunnel, which make it nearly fireproof, and the addition of piling underneath the propeller-shaft supports have placed this equipment in a much more satisfactory operating condition.

The full-scale wind tunnel has been completed and is now in operation. Velocity surveys are being made and several preliminary tests have been conducted on airplanes. During these tests it was found that the tunnel and balances worked very satisfactorily, and a suitable operating procedure is being rapidly established. A rather elaborate survey apparatus is being built by which it will be possible to measure the air-flow velocity and direction about all parts of an airplane mounted in the stream.

BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS.—The aerodynamic activities of the Bureau of Standards have been conducted in cooperation with the Aeronautics Branch of the Department of Commerce and the National Advisory Committee for Aeronautics. The work completed and in progress may be summarized under the following heads:

Reduction of turbulence in wind tunnels.—This investigation was completed and the results described in Technical Report No. 392. The report gives an outline of modern views as to the effect of turbulence and their bearing on the design of wind tunnels. Experiments are described which indicate the effect of certain features of the design on the turbulence.

Transition from laminar to turbulent flow.—Measurements of the speed and turbulence in the flow past a thin flat plate placed parallel to the air stream were brought to completion. The effects of pressure gradient and of initial air-stream turbulence on the transition from laminar to turbulent flow were investigated. The magnitude of the pressure gradient was found to affect the distance from the front edge at which the transition begins, but the thickness of the boundary layer at the transition was nearly independent of the magnitude of the pressure gradient.

The exponent of the power law of variation of the speed with distance from the wall in the turbulent part of the layer was also found to vary with the pressure gradient. The effect of increasing the turbulence was to cause the transition to occur much nearer the leading edge of the plate.

An attempt has been made to account for some of these results on the basis of a new theory of the transition. The mathematical work in connection with this theory is still in progress.

Improvement of apparatus for measuring turbulence.—Considerable effort has been expended to increase the range of frequencies which may be accurately reproduced by the hot-wire anemometer and its associated equipment. As a result of a study of the several elements, investigations of the accuracy of the theory of the behavior of the hot wire, etc., it is now possible to secure a uniform response to frequencies from a few cycles up to 4,000 cycles per second. The inclusion of the higher frequencies in this new equipment has been found to have little effect on the measured mean energy of the turbulence.

Increasing the aerodynamic efficiency of jets.—Because of the interest in jet propulsion, a number of experiments were made to determine whether the thrust reaction of a jet could be increased by the use of deflectors, guide vanes, or by suitable arrangement of the nozzle. The jets used were about 0.25 inch in diameter and pressures up to about 20 pounds per square inch were applied. The nozzles were mounted on a wind-tunnel balance so that the effect of forward motion could be reproduced. Combinations of the jet with airfoils, both straight and ring-shaped, Venturi tubes, deflecting vanes, and streamline bodies have been tried, but no promising results have been secured.

Aerodynamic characteristics of conventional control surfaces.—The results of measurements of hinge moments of ailerons of various chords and spans on 10 by 60 inch models of Clark Y and U. S. A. 27 wing sections at large angles of attack have been published as Technical Report No. 370. Further measurements have been made to clear up disputed points as to the interference between ailerons on opposite wing tips.

Measurements of yawing moments due to rudders of several spans and chords have been completed and the results are being prepared for publication.

Reduction of airplane noise.—An investigation is in progress on the reduction of noise made possible by the muffling of aircraft engines. A test set-up has been provided in which the reduction of noise and the reduction of engine horsepower can be measured.

AERONAUTIC-INSTRUMENT INVESTIGATIONS.—The work on aeronautic instruments was conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department and included the investigations and the development of particular instruments outlined below:

Investigation of damping liquids.—The program of experimental work has been completed and the results are being published as Technical Report No. 398. Data are given in the report on the kinematic viscosity in the temperature range $+30^{\circ}$ to -50° C. of pure liquids and solutions apparently otherwise suitable for

damping. It is shown that the temperature coefficient of kinematic viscosity for the three classes of liquids for which data were obtained is, within about 10 per cent and for a more or less extended temperature range, a function only of the kinematic viscosity.

Temperature coefficient of elastic moduli.—Experimental work has continued on the determination of the temperature coefficient of the elastic moduli of elastic materials for aircraft instruments in the temperature range -50° to $+50^{\circ}$ C. Complete data have thus far been obtained on the temperature coefficient of the modulus of rigidity and the modulus of elasticity of 32 ferrous and nonferrous samples, both when annealed and when strain-hardened or heat-treated to the degree commonly given the material when used to make an elastic element. The coefficient varies greatly with heat treatment in some cases and particularly with the amount of cold work or internal stress. Only second-order differences have thus far been found between the temperature coefficients for the two moduli for a given material.

Reports on aircraft instruments.—A report on instruments for the measurement of the speed of aircraft is practically completed, and a first draft of a report on power-plant instruments has been prepared. Similar reports on altitude instruments and instruments for determining the direction of travel and the attitude of aircraft are in course of preparation. Each report will include the present methods of measurement, the instruments available for use on aircraft, data on the performance of the instruments, and the methods of test in the laboratory.

Friction of pivots.—Additional data have been obtained on the dependence of the friction of steel step and shoulder-bearing pivots in brass bearings upon the finish and the wear of the pivots. As in all investigations of friction, considerable difficulty is experienced in duplicating both test specimens and experimental results.

Present status of air-navigation instruments.—The report on this subject has been published as Technical Report No. 371.

Diaphragm investigation.—A further study of the subject indicated the necessity of obtaining additional data on the relation of drift and time in order to complete the report on The Evaluation of Elastic Afterworking for Instruments with Elastic Elements. An attempt was made to obtain these data by experiments on altimeters, but it appears necessary to supplement these with more precise measurements.

Fuel-flow meter.—An indicator for a fuel-flow meter of the Venturi type in which the fuel was kept confined to the pressure capsules instead of filling the instrument case, was developed and constructed. The new indicator contained two sensitive metal bellows rigidly coupled so that a differential pressure acting

on one caused both to deflect. When each bellows was connected to one of the two Venturi openings their deflection was proportional to the differential pressure developed by the Venturi and when multiplied indicated the rate of flow.

Maximum indicating accelerometers.—Two types of instruments to measure acceleration along the Z-axis were designed and constructed. Each instrument contains an unbalanced weight supported by a helical spring. The indication in one case is obtained by two pointers operating over a graduated dial, one of which is so arranged that it indicates the maximum reading until released. Inertia damping is used, obtained by adding a disk to the pointer shaft. The second instrument is of the cartridge type. The only indication is that of the maximum acceleration, which is obtained by measuring the deflection of a friction pin, the position of which is controlled by the lowest position of the unbalanced weight.

WASHINGTON NAVY YARD

At present the wind-tunnel equipment at the Washington Navy Yard consists of an 8 by 8 foot closed-circuit closed-throat type which is continuously employed on current design work for the Bureau of Aeronautics. A new 6-foot closed-circuit open-throat type has been installed during the past year and calibration tests are now under way. The new tunnel is intended to be used for airplane-model tests exclusively, although other tests may be made if found desirable. A balance of the Zahn type, similar to the one used in the 8-foot tunnel, is being constructed for the new tunnel. Calibration tests show that a speed of 120 miles per hour is attained with about 250 horsepower. There is considerable question as to the ability to use speeds above 80 miles per hour, however, due to excessive vibration from the motor-propeller unit. Some trouble has been encountered with objectionable air currents in the test section and certain modifications are being tried to remedy this condition prior to completion of the balance.

The work of the Washington Navy Yard is concerned almost entirely with design problems submitted by the Bureau of Aeronautics, although tests of a research nature are made from time to time. Routine tests on airplane models constitute approximately 90 per cent of the work. Such tests are made on practically all designs submitted for naval use, and include investigation of stability and control.

MATÉRIEL DIVISION, ARMY AIR CORPS

Routine wind-tunnel model tests.—The usual lift, drag, and moment tests were made on models of the B/J XP-16, Boeing XB-901 (two models), Curtiss XA-8, Martin XB-907 (two models), and Douglas XO-36 airplanes.

Performance data.—A record of the predicted and actual performance of Army airplanes has been compiled. This record includes as far as possible the manufacturer's estimate, the Matériel Division's estimate, and the flight-test results.

Performance studies.—Several studies have been made to determine the effects on the performance of existing airplanes of various changes in the power plant, propeller, wing loading, etc.

A study was also made to determine the effect of changes of horsepower on the high speed of pursuit airplanes with a view to predicting a practical limit for the increase of power.

Low-wing monoplane effects.—A wind-tunnel study was made for the purpose of determining the best practical means for minimizing the undesirable characteristics of the low-wing monoplane. The portion of the wing directly in front of the tail assembly was first modified by the addition of permanent slots, then by a reversal of the rear portion of the mean camber line.

Handbook of instructions for airplane designers.—The handbook has been revised for the purpose of bringing the material up to date and of changing from engineering to absolute units.

Officers' school.—A 2-weeks' course of instruction in wind-tunnel operation was given for the Air Corps Engineering School class.

Oleo shock absorbers.—Routine tests were made on several experimental and service-type oleo shock absorbers in the jig and in flight. This has led to the redesigning of the metering mechanisms in some cases.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

ORGANIZATION

The committee on power plants for aircraft has recently suffered the loss of its chairman, Dr. Samuel W. Stratton, by his death in Boston on October 18, 1931. Doctor Stratton had served continuously as chairman of the committee on power plants for aircraft since its organization under the name of the motive power subcommittee in June, 1916. He exerted a marked influence in the formulation of programs of power-plant research, especially during the war period, and with his experience as an organizer he did much to promote cooperation between the various governmental agencies concerned with the problems of aircraft-engine development. The National Advisory Committee for Aeronautics, at its annual meeting held the day following Doctor Stratton's funeral, recorded an expression of its sorrow at his death and its sincere appreciation of his long and faithful service, including his leadership of the power plants committee, as well as his other service to the committee.

The vacancy in the chairmanship of the committee on power plants for aircraft has not yet been filled, and in the meantime the activities of the committee are being continued under the leadership of the vice chairman, Mr. George W. Lewis.

The present membership of the committee on power plants for aircraft is as follows:

George W. Lewis, National Advisory Committee, for Aeronautics, vice chairman.

Henry M. Crane, Society of Automotive Engineers.

Prof. Harvey N. Davis, Stevens Institute of Technology.

Dr. H. C. Dickinson, Bureau of Standards.

Carlton Kemper, National Advisory Committee for Aeronautics.

Capt. E. R. Page, United States Army, Matériel Division, Air Corps, Wright Field.

Commander C. A. Pownall, United States Navy.

Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

FUNCTIONS

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power-plant research are the most important for investigation by governmental and private agencies.

2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.

3. To act as a medium for the interchange of information regarding aeronautic power-plant research in progress or proposed.

4. To direct and conduct research on aeronautic power-plant problems in such laboratories as may be placed either in whole or in part under its direction.

5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power-plant research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power-plant investigations undertaken by the Army Air Corps or the Bu-

reau of Aeronautics are reported upon at the meetings of the committee on power plants for aircraft.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

COMPRESSION-IGNITION ENGINES.—Recent tests made for the purpose of decreasing the fire hazard in carburetor-type aircraft engines by cooling the exhaust manifolds and by preventing the ignition of gasoline vapors by a back-fire from the engine have substantiated the committee's contention that the most promising method of eliminating the fire hazard in aircraft is to install engines which use low-volatile fuels such as Diesel oil. Although there are available several aircraft compression-ignition engines, the power output per cubic inch of displacement of these engines does not compare favorably with carburetor-type engines. The work of the committee on compression-ignition engines is therefore directed toward increasing the specific power output of this type of engine. The investigation of the factors influencing the injection and combustion characteristics of fuel sprays in compression-ignition engines has been continued. The results indicate that sufficient information on the injection characteristics of fuel sprays has been obtained by the committee's laboratory and other research laboratories to warrant the concentration of further work upon the determination of the combustion characteristics of fuel sprays.

Analysis of indicator diagrams.—The variations in pressure within the cylinders of compression-ignition engines during combustion are being recorded with a modified Farnboro indicator. These indicator diagrams are of assistance in determining the effect on combustion of such factors as fuel quantity, rate of fuel injection, direction and rate of combustion, air movement, and injection advance angle. A method has been developed for analyzing these indicator diagrams, which takes into consideration the variation in weight and composition of the mixture and the changes in specific heat, temperature, pressure, and volume during the engine cycle. This method has been applied to the analysis of a series of indicator diagrams taken for variable fuel quantities, but having the start of injection maintained constant. Under these conditions the results showed that the time lag of injection was practically constant, that the position of maximum rate of effective combustion preceded the position of maximum pressure, and that the combustion efficiency decreased with fuel quantity. A report of these tests is being prepared for publication.

Another series of indicator cards was analyzed according to the tangent method developed by Schweitzer. The analysis shows that in a quiescent combustion chamber increasing the time lag of auto-ignition increases the combustion efficiency of the engine, but also increases the tendency for detonation

to occur, because of the increase in the maximum rate of combustion. The results show that by increasing the air temperature during injection the start of combustion can be forced to take place during injection and so prevent detonation. The rate of fuel injection is shown to have little effect on the rate of combustion. The results of this study are being published as Technical Report No. 401.

Combustion chamber investigation—Integral type.—As previously reported, the principle of proportioning the area of the individual orifices of a multiorifice injection valve to the volume of air served by the spray has been adapted for combustion chamber shapes having little or no air flow. The effect of orifice size and number on the performance of a compression-ignition engine has already been determined. A series of tests was conducted in which the angle between the orifices of a 6-orifice nozzle was varied from 20° to 29° by 3° increments. Although these tests showed that the angle between the fuel sprays was not critical, 25° was chosen as the optimum angle.

Since the full-load performance of a compression-ignition engine is dependent upon the weight of air charge inducted, a method of increasing the power output is to supercharge the engine. A series of tests was made in which the inlet air pressure was varied from atmospheric to 8.75 inches of mercury. The engine operation became very smooth during these tests, and it was possible to advance the start of fuel injection beyond the limit formerly set by allowable knock conditions. With a supercharging pressure of 8.75 inches of mercury the net brake mean effective pressure developed by a single-cylinder test engine at 1,500 revolutions per minute was 26 per cent greater than the full-load performance unsupercharged.

An analysis of the indicator diagrams taken during these tests showed the desirability of initiating combustion as early as possible in the injection cycle. To increase the temperature of the combustion air at the time of injection, the compression ratio of the engine was increased from 12.6 to 15.6. As a result of this increase in compression ratio the full-load brake mean effective pressure of the engine has been increased 8.2 per cent.

Combustion-chamber investigation—Auxiliary-chamber type.—A new test engine has been installed for the work on the auxiliary-chamber type of combustion chamber. The cylinder head for this test engine is designed so that the spherical auxiliary chamber is formed by a cap and a removable insert in the cylinder head proper.

The first tests with this cylinder head have been made to determine the effect of the size of the auxiliary chamber on engine performance. The range of sizes included spherical auxiliary chambers which contained 20, 35, 50, and 70 per cent of the total clear-

ance volume at a constant compression ratio of 13.5. The air flow was axial in direction and was directed at the fuel-injection-valve nozzle. The directing nozzle was so dimensioned in each case that the calculated air velocity was the same for each size of auxiliary chamber. The results of the performance tests indicate that the 50 per cent auxiliary chamber is best suited for further work on this type of combustion chamber. The performance obtained approached, but did not exceed, that of the auxiliary combustion chamber with tangential air flow reported in Technical Note No. 396.

Fuel-spray characteristics.—The investigation of the effect of orifice length-diameter ratio on the characteristics of fuel sprays has been completed and a report prepared for publication. Orifice diameters from 0.008 to 0.040 inch have been tested. When a plain stem was used in the injection valve and the length-diameter ratio increased from 0.5 to 10.0, the spray penetration at first decreased reaching a minimum between the ratios of 1.5 and 2.5; then increased, reaching a maximum between the ratios of 4.0 and 6.0; and decreased again as the ratio was increased to 10.0. The exact position of the maximum and minimum points approached the ratio of zero as the orifice diameter was increased. The spray cone angle varied inversely as the penetration. With a helically-grooved stem in the injection valve a maximum was reached at a ratio between 5.0 and 8.0. The spray cone angle increased as the ratio of groove area to orifice area was increased.

An investigation was conducted to determine the effect of an open nozzle on the spray characteristics. The results showed that for injection systems in which the rate of pressure rise at the discharge orifice is high, open nozzles give spray tip velocities and penetrations which compare favorably with those of closed nozzles. It was found that in designing a system to use open nozzles, particular care must be taken to avoid air pockets and that the check valve should be placed close to the discharge nozzle. The results of this work have been published as a Technical Note.

By means of the N. A. C. A. spray photography equipment, high-speed motion pictures were taken of the formation and development of fuel sprays when directed counter to and normal to air moving at a velocity of 0 to 600 feet per second. The results indicate that in a high-speed compression-ignition engine it is necessary to have air velocities of approximately 300 to 400 feet per second to break up the center core of a fuel spray from a single round-hole orifice. The results showed that high air velocities are an effective means of mixing the fuel and air.

The atomization and distribution of fuel sprays from automatic injection valves have been determined by catching the fuel drops on smoked-glass plates and

then measuring and counting the impressions made in the lampblack. The experiments were made in an air-tight chamber in which the air density was raised to values corresponding to engine conditions. It was found that each spray is composed of several million drops whose diameters range from less than 0.00025 inch to 0.0050 inch and sometimes to 0.0100 inch. The effects of injection pressure, chamber air density, orifice diameter, and orifice length-diameter ratio on the fineness and uniformity of the atomization from plain round-hole orifices were measured and the results compared with those obtained by previous investigators. The atomization of centrifugal sprays, of sprays produced by the impingement of two jets, and of a spray striking a metal lip was also measured and compared with the atomization of sprays from plain nozzles. The experiments indicate that with a given fuel the fineness and uniformity of the atomization increases with the injection velocity and with a decrease in the orifice size. Orifice length-diameter ratio and chamber air density were found to have no decided effect. Centrifugal and impinging sprays were found to have no better atomization than sprays from plain nozzles, provided the injection velocity was the same; the distribution was, however, much better. The results of these experiments have been prepared for publication.

Because of the interest being shown in the substitution of a fuel pump for the carburetor on the conventional spark-ignition aircraft engine, a series of tests was made to determine the characteristics of gasoline fuel sprays for injection pressures from 100 to 500 pounds per square inch and for air densities of atmospheric and 0.325 pound per cubic foot. It was found that the penetration at these low injection pressures and air densities compared favorably with the penetration at high injection pressures. The spray cone angles were small, varying from 2° to 15°, and individual fuel drops were visible in the sprays. The gasoline and Diesel-fuel sprays had similar characteristics.

Fuel-injection systems.—The research started last year on the hydraulics of fuel pumps for compression-ignition engines has been completed and the results are being published as Technical Report No. 396. The effect of various injection valve-opening pressures on the spray tip penetration has been determined for several injection pressures. A common-rail fuel-injection system was used in these tests. For a given injection pressure a maximum rate of penetration was obtained with a valve-opening pressure equal to the injection pressure. As the excess of the injection pressure over the injection valve-opening pressure was increased the effect of the injection valve-opening pressure on the spray tip penetration was increased. These results have been prepared for publication.

An investigation has been conducted on the formation and duration of fuel sprays from a pump injection system. The results show that the penetration of the spray tip, the time lag of injection, and the duration of injection can be controlled by the dimensions of the injection tube, the area of the discharge orifice, and the injection valve-opening and closing pressures. Under ordinary conditions the spray characteristics were satisfactory. At low speeds, such as experienced in starting and in idling, the injection consisted of a series of sprays of short duration following each other in rapid succession. These data have been prepared for publication.

An apparatus has been designed and constructed for determining the instantaneous rates of fuel discharge from a pump injection system. A series of tests has been started to determine the effect of injection-tube length, injection-tube diameter, discharge-orifice diameter, injection valve-opening pressure, pump speed, and similar factors on the instantaneous discharge rates. It has been found that with a well-designed pump the rates of fuel discharge are affected by changes in the above-mentioned factors, but that the total fuel quantity discharged remains nearly constant.

Fuel-spray combustion apparatus.—During the year an apparatus has been completed for recording photographically the spray formation and combustion in a high-speed compression-ignition engine. The apparatus consists of a single-cylinder test engine unit, an electric-drive motor, a fuel-injection system driven from the engine crankshaft, and the N.A.C.A. high-speed photographic equipment. The combustion chamber of the engine consists of a flat disk 3 inches in diameter by 0.875 inch thick. The sides of the chamber are glass windows with a free diameter of 2.5 inches. Some preliminary tests show that the penetration of the sprays into the highly heated and dense air is slightly less than the penetration of the sprays into cold air at the same density. Photographs taken with the combustion starting after the end of injection show that the combustion takes place nearly simultaneously throughout the chamber. Photographs taken with the combustion starting during the injection show that the combustion starts around the edge of the spray, but does not spread throughout the combustion chamber until after cut-off.

FIRE HAZARD IN AIRCRAFT.—*Carburetor intake-system back fire.*—The problem of confining carburetor intake-system back fires was effectively solved. The factors influencing the operation of a type of flame arrester consisting of a pack of alternate flat and corrugated plates inserted in the intake pipe between engine and carburetor were investigated. An analytical study of the heat-transfer and air-flow phe-

nomena demonstrated that the length-diameter ratio of the individual passages of the arrester was the factor of first importance in determining the effectiveness of the device, and that the heat capacity and thermal conductivity of the material of which it was made were only of secondary influence. An arrester was constructed and was found in actual test to prevent an indefinite number of back fires from reaching the carburetor. Air-flow and power measurements showed that the increase in engine-pumping loss due to the presence of such an arrester was negligible, and that the decrease in volumetric efficiency was of the order of a few per cent.

Air-inducting exhaust manifold.—The danger of fuel or oil coming in contact with the heated exhaust manifold of an aircraft engine, especially in a crash, is a serious fire hazard. During the past year the problem of reducing the temperature of the manifold below the ignition temperature of the fuel has been investigated. An "air-inducting" exhaust manifold was constructed and tested on a Pratt and Whitney Wasp engine. Cooling air was taken into the exhaust manifold through a bell-mouthed opening near the exhaust port of each cylinder. The inducted air cooled the exhaust gases and the exhaust stack. The temperature of the air-inducting manifolds was from 200° to 400° F. lower than that of the original manifolds; the exhaust gas temperatures were reduced a greater amount. A technical note presenting the results of this investigation has been published.

Hydrogenated safety fuels.—In connection with the investigation of reducing the fire hazard in aircraft engines using gasoline, fuels having a higher flash point than gasoline have been investigated. The recent developments in the process of manufacturing hydrogenated fuels have made available a large number of "safety fuels." These safety fuels have flash points of 120° F. and can not be readily used with present carburetors. To overcome this difficulty the fuels are being injected into the cylinder of an N. A. C. A. Universal test engine using a cam-operated fuel-injection pump and an automatic injection valve. With the optimum injection rate used in the tests, the power output with the safety fuel was equal to that obtained when using the carburetor and gasoline, although the fuel consumption was from 5 to 8 per cent greater with the safety fuel. Tests made with these fuels in carburetor engines have indicated that a safety fuel having a flash point of 100° F. might be developed for present aircraft engines. The use of such a fuel would result in a considerable reduction of the fire hazard in aircraft as compared with that present when gasoline is used.

AIRCRAFT ENGINE SUPERCHARGERS—*Clearance tests of Roots supercharger.*—The laboratory test work

started last year to determine the effect on the performance of a Roots supercharger of varying the clearance between the impellers and between the case and the impellers has been completed. Tests were conducted for a range of impeller speeds from 1,000 to 5,000 revolutions per minute at pressure differences of 4 to 15 inches of mercury. For each condition, tip clearances of 0.010, 0.016, and 0.022 inch and end clearances of 0.013, 0.018, 0.026, and 0.033 inch were used. A report of the results of these tests will be prepared for publication.

Comparative performance of superchargers.—The performance tests of the De Palma supercharger at speeds from 2,500 to 6,000 revolutions per minute and at pressure differences of 0 to 15 inches of mercury have been completed. Information has also been obtained regarding the effect of clearance between the steel impellers and between the impellers and the aluminum cases on the performance of the supercharger. A report of this investigation is being prepared for publication.

Performance tests have also been made on a vane-type supercharger (Powerplus) for a range of speeds from 500 to 2,500 revolutions per minute and at pressure differences of 0 to 15 inches of mercury.

INCREASE IN ENGINE POWER.—Two-stroke cycle investigations.—The determination of the performance of a single-cylinder 2-stroke cycle, air-cooled engine having gasoline injection and electric ignition has been continued. The gasoline is injected into the cylinder through an impinging jet nozzle at a point just above the air admission ports. The mixture is ignited by a spark plug in the cylinder head.

With a compression ratio of 5, continuous no-load operation was possible with intermittent firing at speeds as low as 300 revolutions per minute. The standard test speed chosen for this engine was 1,000 revolutions per minute, as the power peaks at 1,100 revolutions per minute. At this test speed the power increased with increase of scavenging pressure up to 10 inches of mercury while the specific fuel consumption remained practically constant. At a scavenging pressure of 8 inches of mercury a maximum net brake mean effective pressure of 131.5 pounds per square inch (2-stroke cycle) with a fuel consumption of 0.72 pounds per brake horsepower per hour was obtained. The best economy performance at 8 inches of mercury and 1,000 revolutions per minute was 111 pounds per square inch net brake mean effective pressure at a fuel consumption of 0.55 pounds per brake horsepower per hour.

Investigation of supercharging at various compression ratios.—The results of this investigation, which included compression ratios from 3.5 to 7.5 and carburetor pressures from 30 inches to 42 inches of

mercury, showed that a net increase in brake mean effective pressure of 5 pounds per square inch was obtained for each inch of mercury increase in carburetor pressure above atmospheric pressure. Within the limits of these tests, the decrease in thermal efficiency with boosting was negligible. The results of this investigation have been published as Technical Report No. 404.

Cooling efficiencies of finned cylinders.—The investigation undertaken to determine the maximum quantity of heat that can be efficiently dissipated from finned metal cylinders to an air stream has been continued. Eight finned test specimens have been obtained with fin pitches of 0.1 to 0.6 inch and with fin lengths varying from 0.375 inch for specimens of 0.1 inch pitch to 1.5 inches for specimens of 0.6 inch pitch. The necessary electrical heating elements and guard rings have been assembled.

Tests have been conducted on one of the finned specimens in which the angle of the air flow to the fins has been varied in successive increments from 0° to 90°. These tests were conducted at air speeds of 23 to 150 miles per hour for a constant heat input of 107 B. t. u. per hour per square inch of cylinder-wall surface. The air speed was also maintained constant and tests made with variable heat inputs of 13, 72, 177, and 248 B. t. u. per hour per square inch of cylinder-wall surface. The results of these tests showed that the most efficient cooling is obtained when the air flow is at an angle of 30° to 45° with the fins. A report of the results of this investigation is being prepared for publication.

Cowling of radial engines.—A technical report presenting the results of all flight tests that have so far been made with low-drag cowlings for radial air-cooled engines has been prepared for publication. The greater part of the tests were made with an XF7C-1 airplane, using six types of outer cowling with three variations of the fuselage nose shape. The addition of outer cowlings to the XF7C-1 airplane resulted in speed increases of 6 to 20 miles per hour, depending upon the type of cowling used and the fuselage shape. In general, the engine temperatures rose as the speed was improved, both of these effects being caused by reductions in the amount of cooling air flowing past the engine cylinders. The use of outer cowlings had very little effect on the performance in climb.

BUREAU OF STANDARDS

Supercharging of aircraft engines.—The program of altitude-chamber tests for the Army Air Corps of the Curtiss D-12 engine, equipped with gear-driven superchargers, was concluded when the 15,000-foot centrifugal supercharger was damaged by failure of

an impeller-shaft bearing under high-altitude conditions. Complete test data at the rated speed of 2,300 revolutions per minute were obtained for altitudes from sea level to 20,000 feet, the mixture ratio being adjusted for maximum power in each case.

Reexamination of data obtained with a 150-horsepower Hispano-Suiza engine (Fourth Annual Report of the National Advisory Committee for Aeronautics, p. 508) showed, for this engine, as well as for the Curtiss D-12 engine, linear variation of brake horsepower with exhaust pressure when air is supplied to the carburetor under constant conditions of temperature and pressure. The curves for the Curtiss engine have been made available to the National Advisory Committee as well as to the Army and the Navy, pending completion of a technical report on the performance of this engine under supercharged conditions. The brake-horsepower correction for exhaust back pressure determined for the Curtiss engine has recently been found to be directly applicable to the correction of approximate altitude tests of a Pratt & Whitney Hornet engine where altitude conditions were maintained only at the carburetor entrance.

Phenomena of combustion.—The latest thermodynamic studies by Wohl of the gaseous explosive reaction at constant volume have been applied to the determination of the relation between the temperature of the explosion and the rate of transformation in homogeneous mixtures of explosive gases at constant pressure. As a preliminary, a higher precision was sought in the determination of final volume than previous workers have been able to attain in their determination of final pressure by manometric methods. This involved simplification and improvement of the experimental apparatus and special precautions to insure homogeneity of each explosive charge. Photographic time-volume explosion records of increased accuracy have been obtained over the entire range of the explosive reaction of carbon monoxide and oxygen and approximate explosion temperatures at constant pressure have been computed. The experiments are being continued with mixtures of carbon monoxide and oxygen in equivalent proportions, to which argon is added as an inert diluent.

Combustion in an engine cylinder.—Results of observations of flame travel and pressure development during combustion of gaseous fuels in a single-cylinder engine under various operating conditions will soon be published as Technical Report No. 399. As aids to the interpretation of the engine experiments, photographic records were made of flame travel across the center of a bomb similar in size and shape to the engine combustion chamber, and a mathematical analysis of the effect of thermal expansion on the movement of flame during gaseous combustion in symmetrical closed containers has also been undertaken. Pre-

liminary measurements have been made of the total infra-red radiation to a wave length of 10μ through a fluorite window placed in the cylinder head, using a stroboscope to follow the variations in radiation through the cycle. Data obtained were sufficiently promising to warrant the construction of a sensitive galvanometer which will be used for further radiation measurements.

Pressures and temperatures in aircraft engines.—A considerable amount of information regarding the effects of fuel, operating conditions, and combustion chamber geometry on pressure development in the engine cylinder is being accumulated in connection with the flame movement and radiation experiments, partial indicator diagrams being made with a balanced diaphragm engine indicator during the compression, combustion, and expansion periods for each run. As a preliminary to obtaining torque measurements and complete indicator diagrams of improved precision for the purpose of comparing "dynamometer" and "indicator card" power, a technical note is being prepared which describes various concepts of indicated power and discusses their significance as applied to 4-stroke-cycle engines.

Effect of spark character on ignition ability.—In order to define spark discharges precisely in terms of their voltage and current characteristics, a cathode-ray oscillograph was obtained. Extended experimentation was required to develop satisfactory methods of measuring voltage and current without appreciably altering the character of the spark. A report on the use of the cathode-ray oscillograph in measuring spark discharges and a second report on the effectiveness of ignition sparks, as measured by the amount of chemical reaction occurring when different sparks are passed through lean mixtures of oxygen and hydrogen at atmospheric pressure, are being written for publication by the National Advisory Committee for Aeronautics. Apparatus has been constructed for continuing at higher pressures the work on the amount of chemical reaction produced by different sparks.

Work undertaken by the ignition laboratory for the Navy Department has included (1) measurements of sparking potential and of the distribution of energy in different spark gaps; (2) the use of absorption spectra to study the effect of temperature on the oxidation of hydrocarbon-air mixtures; and (3) tests of gasoline stability as influenced by exposure to ultraviolet light and passage through a heated metal tube.

Effect of air humidity on engine performance.—Aircraft engine tests with constant air temperature at altitudes from sea level to 25,000 feet showed maximum indicated power to be linearly proportional to dry-air pressure, the average deviation being ± 0.16 per cent. On the basis of these tests and extended tests on other engines, made at the request of the Navy

Department, it was recommended that humidity be recognized as a major factor in engine power variation and it has been proposed (1) that sea-level engine tests be corrected to a total pressure of 760 millimeters of mercury, but a dry-air pressure of 750 millimeters of mercury; and (2) that standard humidities, decreasing from 10 millimeters of mercury at sea level to 0.18 millimeters of mercury at 25,000 feet, be added to the specifications of the standard atmosphere for tests of aircraft engines.

A study of the injection of water spray into the combustion chamber of an engine showed high anti-knock action without loss of power with optimum timing of spark advance and of injection.

Tests at altitudes up to 30,000 feet and over wide ranges of temperature and relative humidity indicate an accuracy better than 0.25 per cent for the modified psychrometer developed during this research.

Vapor lock in airplane fuel systems.—To round out the laboratory work on airplane fuel-feed system design, the efficiency of all types of fuel pumps in general use is being compared under a chosen set of representative operating conditions. Temperature-flow curves have been obtained on the C-5, C-3, and Romec pumps with one kind of gasoline at each of three atmospheric pressures. The Navy seaplane pump and the autopulse pump will also be tested.

Analysis of flight-test data on airplane fuel-line temperatures obtained during the past two years in cooperation with the Army, the Navy, and the National Advisory Committee for Aeronautics showed that in all cases the temperature of the fuel in the feed system tended to drop very slowly as the airplane climbed. To overcome this tendency, fuel tanks should be so installed as to insure good heat interchange with the atmospheric air or else small fuel radiators placed in the air stream should be employed. The temperature of the fuel in the tank as the airplane leaves the ground and the rate of heat interchange with the atmospheric air are factors which outweigh any minor differences in fuel-system design, although much can be done to improve design.

Revised specifications for aviation gasolines, under consideration by the Federal Specifications Board, permit the use of gasoline having a vapor pressure of 10 pounds per square inch in airplanes equipped with fuel systems which are satisfactory as regards vapor lock, while for airplanes with unimproved fuel systems the vapor pressure is limited to 7 pounds per square inch. This emphasizes the desirability of requiring suitably designed fuel-feed systems in all new airplanes.

Gumming characteristics of gasolines.—An investigation of the gumming characteristics of gasolines was undertaken for the Army Air Corps to develop

significant test methods for determining the gum content of gasolines and its tendency to increase during storage. Gum-content data obtained on numerous gasolines by several methods indicated that the measured gum content depends very materially upon the method employed in evaporating the gasoline. Since the air-jet method showed the most promise, an extended study has been made of the variables affecting evaporation by this method. In connection with the tendency of gasolines to form gum during storage, the resistance to oxidation of a number of gasolines has been measured at various temperatures and under various oxygen pressures. Since quantitative relations were found between resistance to oxidation and gum stability under all conditions of test, measurements of resistance to oxidation give promise of being significant as regards gum formation under normal storage conditions.

In the contemplated revision of Federal specifications for aviation gasolines, a specification for gum has been proposed which would replace the present copper-dish test. The gasoline is required to have less than a specified amount of gum after being subjected to accelerated oxidation.

Type testing of commercial aircraft engines.—The aircraft engines tested at the Arlington laboratory showed somewhat greater variety both as to type and size. There were 11 radial engines, including one Diesel; 8 inverted in-line engines; 4 horizontal-opposed engines; and 4 V-type engines, including a 12-cylinder inverted V. Five engines tested had less than 200 cubic inch displacement and three engines had more than 700 cubic inch displacement. Of 27 engines received for test during the year, 14 passed, 11 failed, and 2 were withdrawn. Eight of the engines which failed were new types and three had received one previous test each. Crank-case breakage was the most common source of major failure, three cases being noted. At the end of June, 73 engines had received approved-type certificates from the Department of Commerce.

Each engine is approved only for use with fuels equal or superior to that used during the official test and the important fuel characteristic is its detonation rating or octane number. Preliminary experiments on five aviation gasolines ranging from below 60 to above 80 octane number were undertaken in cooperation with the Army, the Navy, and four industrial laboratories. The fuels were rated by a variety of available methods and the results showed that the detonation rating assigned to an aviation gasoline depends on the test method and equipment used. Further work must be done to determine the particular type of test which gives ratings most indicative of the relative behavior of aviation fuels under actual service conditions.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

ORGANIZATION

The present organization of the committee on materials for aircraft is as follows:

Dr. George K. Burgess, Bureau of Standards, chairman.

Prof. H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.

Lieut. Commander R. S. Barnaby (C. C.), United States Navy.

S. K. Colby, American Magnesium Corporation.

Warren E. Emley, Bureau of Standards.

Commander Garland Fulton (C. C.), United States Navy.

Dr. H. W. Gillett, Battelle Memorial Institute.

C. H. Helms, National Advisory Committee for Aeronautics.

Dr. Zay Jeffries, Aluminum Company of America.

J. B. Johnson, matériel division, Army Air Corps, Wright Field.

George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Capt. Alfred J. Lyon, United States Army, matériel division, Air Corps, Wright Field.

H. S. Rawdon, Bureau of Standards.

E. C. Smith, Republic Steel Corporation.

G. W. Trayer, Forest Products Laboratory, Forest Service.

Starr Truscott, National Advisory Committee for Aeronautics.

Hon. Edward P. Warner, editor of "Aviation."

FUNCTIONS

Following is a statement of the functions of the committee on materials for aircraft:

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally by governmental and private agencies.

2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.

3. To act as a medium for the interchange of information regarding investigations of materials for aircraft in progress or proposed.

4. To direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.

5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of

information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development. Much of the research, especially in the development of light alloys, must necessarily be conducted by the manufacturers interested in the particular problems, and both the aluminum and steel industries are represented on the committee.

Much of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics, and many of the problems are apportioned to the Bureau of Standards for investigation.

SUBCOMMITTEES

In order to cover effectively the large and varied field of research on aircraft materials, subcommittees have been established from time to time under the committee on materials for aircraft. During the past year, in a general reorganization of subcommittees effected by the executive committee, two of these subcommittees, the subcommittee on woods and glues and the subcommittee on coverings, dopes, and protective coatings, were discontinued, and in their stead a new subcommittee on miscellaneous materials was appointed.

Another important change during the past year in the subcommittee organization under the committee on materials for aircraft was the establishment in April, 1931, of a temporary subcommittee on research program on monocoque design as a subcommittee of the subcommittee on aircraft structures. The functions of this new subcommittee are to offer suggestions from time to time as to details of the program of the investigation of stressed-skin construction for aircraft, under way at the Langley Memorial Aeronautical Laboratory, and to present recommendations as to investigations in connection with the problem of monocoque design which can be undertaken by other organizations.

On recommendation of the structures subcommittee and the materials committee, the executive committee has recently provided for the appointment of a standing subcommittee on methods and devices for testing aircraft materials and structures as an additional subcommittee of the committee on materials for aircraft, for the purpose of studying the present methods and devices used in the testing of aircraft materials and structures with a view to standardization and improvement. This subcommittee has just been established and has not yet begun its work.

The present organization of the subcommittees of the committee on materials for aircraft is as follows:

Subcommittee on metals:

H. S. Rawdon, Bureau of Standards, chairman.
 Dr. H. W. Gillett, Battelle Memorial Institute.
 Dr. Zay Jeffries, Aluminum Company of America.
 J. B. Johnson, matériel division, Army Air Corps,
 Wright Field.

George W. Lewis, National Advisory Committee
 for Aeronautics (ex officio member).

E. C. Smith, Republic Steel Corporation.

Starr Truscott, National Advisory Committee for
 Aeronautics.

Prof. H. L. Whittemore, Bureau of Standards.

Subcommittee on aircraft structures:

Starr Truscott, National Advisory Committee for
 Aeronautics, chairman.

Lieut. C. E. Archer, United States Army.

C. P. Burgess, Bureau of Aeronautics, Navy
 Department.

Richard C. Gazley, aeronautics branch, Depart-
 ment of Commerce.

Charles Ward Hall, Hall-Aluminum Aircraft
 Corporation.

Lieut. Lloyd Harrison (C. C.), United States Navy.

Lieut. Paul H. Kemmer, United States Army,
 matériel division, Air Corps, Wright Field.

George W. Lewis (ex officio member).

Lieut. Commander R. D. MacCart (C. C.), United
 States Navy.

Charles J. McCarthy, Chance Vought Corporation.

Prof. J. S. Newell, Massachusetts Institute of
 Technology.

Dr. L. B. Tuckerman, Bureau of Standards.

*Temporary subcommittee on research program on
monocoque design:*

George W. Lewis, National Advisory Committee
 for Aeronautics, chairman.

Richard C. Gazley, aeronautics branch, Depart-
 ment of Commerce.

Lieut. Paul H. Kemmer, United States Army,
 matériel division, Air Corps, Wright Field.

Eugene E. Lundquist, National Advisory Com-
 mittee for Aeronautics.

Lieut. Commander R. D. MacCart (C. C.), United
 States Navy.

Dr. L. B. Tuckerman, Bureau of Standards.

Subcommittee on miscellaneous materials:

Charles H. Helms, National Advisory Committee
 for Aeronautics, chairman.

Dr. W. Blum, Bureau of Standards.

C. J. Cleary, matériel division, Army Air Corps,
 Wright Field.

Warren E. Emley, Bureau of Standards.

George W. Lewis (ex officio member).

J. E. Sullivan, Bureau of Aeronautics, Navy De-
 partment.

G. W. Trayer, Forest Products Laboratory.

P. H. Walker, Bureau of Standards.

G. P. Young, matériel division, Army Air Corps,
 Wright Field.

*Subcommittee on methods and devices for testing air-
craft materials and structures:*

Henry J. E. Reid, Langley Memorial Aeronauti-
 cal Laboratory, chairman.

Lieut. Lloyd Harrison (C. C.), United States
 Navy.

Lieut. Paul H. Kemmer, United States Army,
 matériel division, Air Corps, Wright Field.

George W. Lewis (ex officio member).

R. L. Templin, Aluminum Company of America.

Dr. L. B. Tuckerman, Bureau of Standards.

SUBCOMMITTEE ON METALS

A number of investigations on metals and their applicability have been conducted at the Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics. The Battelle Memorial Institute also volunteered to carry out an investigation on the low-temperature properties of a number of metals which are of importance in aircraft construction.

Properties of metals at low temperatures.—A technical note has been issued giving the results of co-operative tests carried out at the Battelle Memorial Institute on the properties of metals at low temperatures. In addition to steels already in use for aircraft construction, several other metals suggested for corrosion-resistant streamline wire were studied. Monel metal, stainless iron (0.07 per cent carbon, 13.8 per cent chromium), 18-8 stainless steel, 3.5 per cent nickel steel, and chromium-molybdenum steel were used. The endurance limit of the materials at -40° F. was found to be raised in practically the same ratio that the tensile properties and Brinell hardness were. There seems to be no reason to fear premature failure from fatigue at low temperatures. The resistance of notched specimens to impact at the low temperature was materially lowered, however, for some of the materials.

Identification of chromium-molybdenum steel.—Work along chemical lines was continued during the year on a rapid method of distinguishing between chromium-molybdenum and plain carbon steel, both of which, in tubular form, are used in aircraft construction. The attempt to develop a satisfactory chemical "spot" test for molybdenum has been unsuccessful. However, a practical and rapid method to be used on drillings based on the stannous-chloride potassium-sulphocyanate reaction with molybdenum

has been developed. This method appears to be decidedly better than the one used hitherto.

Intercrystalline embrittlement of sheet duralumin.—This work has been continued; the series of weather exposure tests in the three locations, Coco Solo Naval Air Station, Hampton Roads Naval Air Station, and Bureau of Standards, are now in the fifth year. The results of tension tests made on the corroded materials removed periodically from the test racks continue to show the stability of the materials if properly heat-treated. Sheet duralumin which has been given the following treatments has been found to be susceptible to intercrystalline corrosion when exposed to the weather:

Temperature (°C.)	Quench		Temperature, quenching medium	Aging
	Heating period	Quenching medium		
	Minutes		°C.	
500	15	Water	100	Room temperature.
500	15	do	0	3 hours 150° C.
500	15	Oil	25	Room temperature.
500	15	do	0	Do.
500	60	do	25	Do.
425	60	Water	25	Do.
500	60	do	100	96 hours room temperature with 10 per cent stretch.
500	60	do	0	96 hours room temperature and 5 hours 135° C.
500	20	do	25	8 to 15 hours 140° C.

¹ 25S-T alloy.

All of the numerous coating materials used, which are applied by means of a brush, have been found to break down within 36 months' continuous exposure to the weather, the test results secured at Hampton Roads being used as a basis for this statement. Aluminum-pigmented spar varnish was found superior to all other brushed-on coatings used. An aluminum coating which forms an integral part of the sheet as in the Alclad materials has proved far superior to any brushed-on coating in all of the exposure tests.

Of the various methods used for treating the surface of duralumin so as to improve the adherence of coatings to such sheets, the anodic treatment has proved by far the most satisfactory one.

A new series of exposure tests to supplement and extend the present one has been planned. In this will be included materials developed within the period since the first tests were started.

Protection of duralumin, anodic oxidation.—Prompted by the wide commercial use of the anodic oxidation process as a means for increasing the corrosion resistance of duralumin, a study has been carried out during the year on the process. A method for the rapid inspection of the oxide film consisting in

the use of a saturated solution of mercuric chloride has been developed. Films which withstand a 15-minute immersion will meet the requirement laid down in the Navy specifications. The utility of solutions of chromic acid of various concentrations has been studied. Satisfactory coatings can be made with other concentrations besides the commonly used 3 per cent solution. It has been shown that the corrosion resistance of the treated products is not impaired by chromic-acid stains. Heat treatment of duralumin after the anodic film has been formed does not impair the film. Work is being continued on other aspects of the process, especially the useful "life" of the chromic solution in continuous use.

Exposure tests of magnesium and magnesium alloys.—After 24 months' continuous exposure to the weather on a roof at the Bureau of Standards no marked decrease was observed in the tensile strength of the specimens of magnesium and magnesium alloys, nor had the ductility, which was initially relatively low, decreased to any very marked extent.—All of the coatings, however, regardless of the initial surface treatment of the materials, showed evidence of complete "breakdown" by peeling and scaling.

High-frequency endurance tests of light alloy sheet materials.—Work has been continued on this project throughout the year, the seven units of air-driven high-frequency endurance-testing machines at the Bureau of Standards being utilized for the purpose. Of the 14 materials initially available for study, it has proved possible to determine the endurance limit of the nine materials which possess well-defined elastic properties. These results are summarized in the table. Annealed material could not be tested by this method. Attempts to determine the endurance limit for the following were unsuccessful: 2SO (annealed aluminum), 3SO (annealed aluminum-manganese alloy, 1.25 per cent Mn), MO (annealed magnesium), and 17SO (annealed duralumin). Likewise it was impossible to stress Alclad duralumin, which consists of a sheet of heat-treated alloy (17S) with a layer of pure aluminum on each surface integral with it, sufficiently in the machine to cause failure, whereas the plain heat-treated sheet without the surface layers of aluminum was readily tested. It has not been found possible to develop sufficient stress in steel-sheet specimens so that the endurance limit could be determined by this means. Consequently the projected work on welded steel has been laid aside.

The possible effect of the anodic oxidation treatment on the fatigue properties of duralumin still remains to be determined. Preliminary tests indicated no marked change in the properties resulting from this treatment.

Endurance limit of light alloy sheet materials by high-frequency flexure, 12,000 cycles per minute

Designation	Treatment	Nominal composition	Direction of specimen ¹	Endurance limit (pounds per square inch)
17ST	Heat-treated and aged	Cu 4.0, Mn 0.5, Mg 0.5, Al remainder	L and T	15,000
25ST	Fully heat-treated	Cu 4.5, Mn 0.8, Si 0.8, Al remainder	L	14,000
25ST	do	do	T	15,000
25SW	Quenched, not aged	do	L	11,000
25SW	do	do	T	13,000
51ST	Fully heat-treated	Mg 0.6, Si 1.0, Al remainder	L and T	13,000
51SW	Quenched, not aged	do	L	10,500
51SW	do	do	T	13,000
2SH	Cold-rolled	Aluminum, commercially pure	L and T	10,000
3SH	do	Mn 1.25, Al remainder	do	12,000
MH	Hard-rolled	Magnesium, commercially pure	do	6,000
MAH	As rolled	Al 4.0, Mn 0.4, Mg remainder	do	5,000-6,000

¹ L, longitudinal, parallel to direction of rolling. T, transverse, perpendicular to direction of rolling.

Fatigue of Alclad duralumin.—Work on this project was continued at the Bureau of Standards during the past year. The test method used differs from that referred to elsewhere in this report in that a motor-driven endurance-testing machine for repeated flexure at a cycle frequency of 900 revolutions per minute was used. The results previously reported have been reviewed and checked and the following values are the approximate stresses for a life of 100,000,000 cycles:

	lbs./in. ²
Regular 17ST (uncoated duralumin) heat-treated, longitudinal	16,000
Regular 17ST (uncoated duralumin) heat-treated, transverse	14,000
Alclad 17ST heat-treated, longitudinal	10,500
Alclad 17ST heat-treated, transverse	10,500
Special 17ST (uncoated duralumin) heat-treated, longitudinal	19,000
Special 17ST (uncoated duralumin) heat-treated, transverse	21,000
Alclad special 17ST, heat-treated, longitudinal	13,000
Alclad special 17ST, heat-treated, transverse	11,200

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Strength of welded joints in tubular members for aircraft.—The joints which will be tested in the second program of this investigation, sponsored by the National Advisory Committee for Aeronautics, are at the present time being welded. Special attention is being paid to the cause and prevention of cracks in welding this series of joints. It seems possible to eliminate all but a very few of such cracks by correct design and technique.

The type of gusset reinforcement which was found to be strongest has been improved to eliminate high residual stresses which produce cracks. No cracks have been noted in the improved joint. For the detection of cracks a magnetic flux is passed through the specimen and powdered iron dusted on it. The technique used is that developed by A. V. DeForest. Any cracks, seams, or other discontinuities present are

indicated by an accumulation of the powder clinging to the edges of the cracks.

All the tubing was inspected by this method before welding and a number of indications of longitudinal seams were found which were not detected on visual inspection. It is believed that the majority of such seams are not deep enough to lower materially the strength of the tubing in tension or compression, but might lower the torsional strength. Tests will be made to determine the effect of such seams on the strength of the tubing. After welding, all of the joints will be inspected by the same method.

A series of joints is being made in tubing 1.5 inches in diameter and 0.020 inch in wall thickness. Tests will also be made on a group of joints to be heat-treated after welding.

Form factors for tubing of duralumin and steel under combined column and beam loads.—The extended series of tests covering tubes of duralumin and chromium-molybdenum steel having outside diameters of 1 inch, 1.5 inches, and 2 inches and having ratios of outside diameter to wall thickness ranging from about 15 to 60 has been completed, and the results are being prepared for publication.

The tests over this wider range have confirmed within experimental error the relations between modulus of rupture, tensile yield point, and strength of the tubes found in the previous tests and published in Technical Note No. 307 of the National Advisory Committee for Aeronautics. The results given in that publication are therefore valid within the limits stated.

The extended series of tests, however, showed that over the wider range of diameter-thickness ratios the ratio of the modulus of rupture to the tensile strength varied too widely to allow the choice of a reasonably representative value for all diameter-thickness ratios, as was done in the design charts, Technical Note No. 307, covering a more limited range of d/t values. At

$l/r=30$ the modulus of rupture, for duralumin tubes of 55,000 pounds per square inch tensile strength, ranged from 43,000 pounds per square inch at $d/t=60$, to 58,000 pounds per square inch at $d/t=15$. For chromium-molybdenum tubing the variation was even greater, ranging for tubes of 95,000 pounds per square inch tensile strength from 78,000 pounds per square inch at $d/t=60$, to 130,000 pounds per square inch at $d/t=15$.

Although no theoretical basis for this variation has been worked out, the tests covered a sufficient range to give reliable empirical relationships between tensile strength, modulus of rupture, slenderness ratio, and diameter-thickness ratio for these two materials. At present a study is being made of the best method of combining the results in conveniently usable design charts.

When this work is completed further investigation of the relationship between the tensile properties and modulus of rupture of the tubes will be taken up in an endeavor to discover a theoretical basis for the results.

Torsional strength of tubing.—A series of tests has been completed on chromium-molybdenum tubing of diameter-thickness ratios ranging from 12.5 to 57. The shortest specimens tested were 19 inches long; the longest specimens, 5 feet. All failures were buckling failures in the plastic range.

The tubing supplied showed marked differences in physical properties, the tensile strengths ranging from 88,000 to 133,000 pounds per square inch. Examination of the stress-strain curves showed that the material could be grouped into two distinct classes, one with a rather sharp break in the stress-strain curve and the other with a gradual curve as the material passed from the range of elastic into the range of plastic deformation.

The results of the torsion tests confirmed this grouping. The ratios of the torsional strength to the yield point of the material, determined according to proposed revision to Navy Department Specification 44T18a, July 1, 1931, fall into two groups. For the material with a sharp break in the stress-strain curve the ratios decrease with increasing diameter-thickness ratio, the decrease being approximately 8 per cent from $d/t=20$ to $d/t=45$. For the material with gradual curvature the ratios are greater at low diameter-thickness ratios, but decrease approximately 40 per cent over the same range, reaching about the same value as the other group at $d/t=45$.

Below $d/t=45$ there was, for the materials with a sharp break in the stress-strain curve, no noticeable effect of tube length, but above $d/t=45$ there was a small but noticeable decrease of strength with increasing length of tube.

Within the limits of the sizes tested it seems safe to design chromium-molybdenum torque tubes for a

maximum shearing stress equal to $1/\sqrt{3}$ times the tensile yield point of the material, determined according to proposed revision of Navy Department Specification 44T18a, July 1, 1931. This does not take advantage of the full strength of one group of material at low diameter-thickness ratios, but without modification of the specification it would be unsafe to design for material of that type.

A series of tests has been started on duralumin tubing having diameter-thickness ratios ranging from 8 to 90. It is expected that because of the uniformity of this material, as evidenced by past tests, more certain progress can be made in the analysis and correlation of the data.

Airship girders and airship structural members.—The study of the twisting type of failure found in column tests of open sections used as chord members of airship girders has been resumed. The twisting failure depends upon the torsional rigidity, and also upon the axis about which the section twists.

Theoretical and experimental investigations reported in technical literature suggest that the axis of twist under column load may coincide with the axis of shear determined in beam theory. In open sections this axis does not, in general, coincide with the axis of twist under uniform torque.

Experiments have been made on duralumin channels (A.3) of the type used in the triangular girders of the *Shenandoah*, in which a specimen was twisted at mid-length. The results indicated that the axis of twist was not constant in position, but lay outside the section and closer to it than the computed axis of shear.

The location of the axis for pure twist is not being determined experimentally.

An analytical study of the secondary longitudinal stresses set up in the channel subjected to twist is being made. These stresses become of special importance at large angles of twist, and their distribution is dependent upon the location of the axis of twist.

The tests on small preformed wire terminal loops made by the Goodyear-Zeppelin Corporation by the same method as was employed in making the loops for the ZRS-4 and ZRS-5 have been continued. As the largest diameter of these loops is about 0.875 inch, measurements of the change in curvature for various loads are difficult; 3,415 individual measurements of curvature on four specimens have been made at various loads up to approximately 700 pounds.

Maximum stress differences, calculated according to the Winkler curved-beam theory, of approximately 557,000 pounds per square inch, corresponding to a load of 450 pounds, have been found in one of the less perfect loops. For the more perfect loops the stresses were only about 60 per cent as great.

These stress differences are surprisingly high and emphasize the importance of careful design and workmanship in terminal wire loops.

A number of pieces of duralumin channels and lattices taken from the U. S. S. *Los Angeles* for the annual inspection have been tested. The results confirm previous studies, which indicated that, although there was a slow progress in corrosion since the previous sampling, no sample was found in which the corrosion had progressed enough to reduce the strength of the girders below the design values.

Tensile coupon specimens of thin sheet Alclad about 0.0095 inch thick, which had been cut from the metal-clad airship (*MC-2*), have been tested. The metallographic examination showed slight traces of corrosion, but the tensile tests showed no measurable deterioration. No specimen tested had less than 31,500 pounds per square inch yield point, 54,600 pounds per square inch tensile strength, or 16 per cent elongation.

End fixation of struts.—The investigation has been continued this year with the testing of three more complete series of chromium-molybdenum tubes 1.5 inches in diameter and 0.058 inch thick. Restraints of 250,000, 330,000, and 451,000 pound inches per radian of rotation of the fixture at each end were used. The slenderness ratios varied from about 30 to 150. Each specimen was tested in duplicate.

It was found as a result of these tests that by applying the Considère-Engesser theory of column action the strength of a column with any given equal elastic restraint at the two ends could be predicted from the strength of a freely supported column. This fact will result in the saving of an appreciable amount of work in the laboratory and should hasten the completion of the investigation.

Technique of testing flat plates under normal pressure.—Contours and deflections at the center, due to permanent set, were measured on a series of 17-ST duralumin plates with clamped edges of sizes 5 by 5 and 7.5 by 7.5 inches and of thicknesses ranging from 0.01 to 0.065 inch. A number of 5 by 5 inch plates with supported edges were tested in the same way. The results could not be brought into close agreement with existing theories, but it proved possible to describe them by empirical formulas.

A detailed analysis of the contours showed that the square plates with clamped edges were most highly stressed in bending close to the edges near the center line, while those with supported edges were most severely bent along the diagonals close to the corners.

Permanent deformation is thus produced near the edges at loads which produce only very small stresses in the central portion of the plate.

A device has been constructed for observing deflection at points 0.05 inch apart in these highly stressed portions of the plate. The tests are at present being

extended to the longer plates, i. e., 7.5 by 17.5 and 5 by 30 inches.

Inelastic behavior of duralumin and alloy steels in tension and compression.—The tests to determine the relative physical properties in tension and compression of metals used in aircraft structures have been continued. These structures are often fabricated from thin-walled tubing or from thin sheet which has been cold worked after heat treatment. Many tensile tests have been made, some of which show significant differences in the character of the stress-strain curves for specimens taken with and across the direction of rolling.

It is difficult, however, to obtain satisfactory results for the physical properties of thin material in compression because the specimens usually fail elastically by bending before the plastic range of the material is reached. Satisfactory results may be obtained either by preventing the bending by external forces or by testing a sufficiently short specimen.

Two 1-inch Tuckerman optical strain gauges are now available so that compression tests can be made on specimens 1.5 inches long. A procedure has been developed for testing specimens of circular cross section, wherein, by successive adjustments, the strains as measured by the two gauges on opposite sides of the specimen do not differ by more than 0.00001 inch.

TEMPORARY SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

Stressed-skin structures.—For some time it has been evident that designers and manufacturers who desire to use the stressed-skin, or monocoque, type of construction for the fuselage or other parts of airplanes have difficulty in finding sound theoretical methods of analysis and reliable experimental data. A survey was initiated for the purpose of learning what methods and data were available and used in design. This survey was conducted by Mr. Eugene E. Lundquist, of the staff of the Langley Memorial Aeronautical Laboratory, and showed that as a rule the methods of design were empirical and depended upon tests being made on full-scale examples of the structure under investigation. There was little theory, and in general the information was scattered, uncorrelated, and often unavailable.

Under the direction of the temporary subcommittee on research program on monocoque design, a survey has been made of the available data on the compressive strength of stiffeners of various forms as used in stressed-skin construction. Much of this data was of dubious value because of the neglect to include information regarding the properties of the materials. However, as a first result of this survey a technical note is being prepared on the column strength of duralumin angles with equal legs. This will include a chart giving values for the more common sizes.

A series of tests made at the Langley Memorial Aeronautical Laboratory on cylinders of paper and celluloid indicated that valuable information could be obtained from tests of larger thin-walled cylinders of duralumin. Accordingly, a program for these tests was prepared, and they are now under way at the laboratory. The conditions of loading will include compression, torsion, pure bending, combined shear and bending, and additional combinations of loadings. Under these varied conditions of loading the effect of systematic variation in the spacing of bulkheads, thickness of shell, or skin, and the diameter of the cylinders will be investigated.

The results of the tests already made indicate that the distance between bulkheads has a marked effect on the strength of thin-walled cylinders, especially on the strength in shear. Also, it has been found that the bending strength of a cylinder in pure bending may be as much as 20 per cent less than the bending strength in combined shear and bending at large values of the moment shear ratio, even though the type of failure may appear to be the same.

These tests are expected to furnish a guide for the preparation of a program of further research on the strength of reinforced shells and also to supply data by which to judge the efficiency of various types of reinforcement. A technical note now in preparation will present the results of the tests which have been made and will include a summary of similar tests made by manufacturers and others.

The tests have emphasized the importance of full information as to the properties of the materials of which test specimens are made. It is particularly important in the thin materials and in the stressed-skin construction. The Bureau of Standards has made a study of the properties of the duralumin sheet used in the construction of the cylinders and cones now being tested at the Langley Memorial Aeronautical Laboratory. The tests thus far have been made on sheet duralumin 0.011 inch thick and indicate that, for practical purposes, the modulus of elasticity is the same in all directions but that the yield point and ultimate strength in the direction normal to the direction of rolling are approximately 88 and 95 per cent, respectively, of the corresponding values parallel to the direction of rolling.

A report presenting the results of this investigation will probably be prepared when more data are available.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS

Gas-cell fabrics.—The search for a durable and flexible membrane of low permeability to hydrogen and helium, to supersede goldbeater's skin in gas-cell construction, has led to the development of a fabric

consisting of rubberized cloth on which are spread several layers of a gelatin-latex mixture. This fabric has proved very satisfactory from the standpoint of performance, and it represents a marked reduction in the cost of production compared to the old goldbeater's-skin fabric. One-half of the gas cells of the U. S. S. *Akron* are constructed of this new fabric.

Since gas cells are subjected to tear due to handling and to the motions they undergo in their compartments in the airship, the problem of increasing the tear resistance of the cloth without change in its strength-weight ratio is being investigated. Several cloths have been woven using different constructions as to weave and yarn. The first samples have shown an increase in tear resistance of about five times that of the ordinary balloon cloth.

Study of mercerization of cotton for aeronautical uses.—The broad purpose of this investigation is the improvement of domestic cotton textiles for aeronautical uses. One of the principal requirements of airplane wing-cover cloth, balloon cloths, parachute cloth, webbings, etc., is maximum strength for a given weight. The strength-weight ratio for cotton yarns and cloths depends primarily upon the kind and staple length of the cotton, the size, twist, and ply of the yarn, and the mercerization process. Of these, mercerization especially requires investigation, because ordinary commercial mercerization is concerned with luster and appearance rather than with increase in strength-weight ratio.

Apparatus for the mercerization of yarn under strictly controlled conditions has been built and a study of the factors in the mercerization process which affect the properties of yarn has been completed. The factors under consideration were the tension on the yarn during mercerization, the strength of the alkali used, the temperature maintained during the process, and the time of mercerization. The optimum conditions resulted in an over-all increase in the strength-weight ratio of the yarn of 40 per cent based on the gray yarn. Twenty-five per cent of the increase resulted from the treatment of the yarn before mercerization. The effect of the twist in the yarn on the strength-weight ratio after mercerization is now being studied. Further consideration is being given to pretreatments.

Substitute for silk cloth for parachutes.—A technical note entitled "An Investigation of Cotton for Parachute Cloth" has been published. In this note appear the specifications for the material and construction of a cotton cloth which will meet parachute requirements as regards weight, strength, bulk, and satisfactory operation.

This investigation is being continued. Two cotton cloths of different construction are about ready to be

fabricated into parachutes and will be given performance tests in comparison with the standard parachute using silk.

Woods and glues.—The final report of the series prepared by the Forest Products Laboratory covering the investigations of wood in aircraft construction has been published. This report discusses two fundamental problems of elastic instability of members having sections common in aircraft. Formulas are given for calculating the critical stress at which a thin outstanding flange of a compression member will either wrinkle into several waves or form into a single half wave and twist the member about its longitudinal axis. These formulas were mathematically derived and the experimental verification is given in the report.

REPORT OF COMMITTEE ON PROBLEMS OF AIR NAVIGATION

ORGANIZATION

In response to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, particularly in the fields of navigation instruments, aerial communications, and meteorological problems, the National Advisory Committee for Aeronautics in 1928 established a new standing committee on problems of air navigation, with members representing the principal agencies concerned with the development of aids to air navigation.

The committee on problems of air navigation is at present composed of the following members:

Hon. William P. MacCracken, jr., chairman.
 Dr. L. J. Briggs, Bureau of Standards.
 Lloyd Espenschied, American Telephone & Telegraph Co.
 Brig. Gen. B. D. Foulois, United States Army, Air Corps, War Department.
 Paul Henderson, National Air Transport (Inc.).
 Capt. S. C. Hooper, United States Navy, director of naval communications, Navy Department.
 Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
 Col. Charles A. Lindbergh.
 Prof. Charles F. Marvin, Weather Bureau.
 Lieut. J. P. W. Vest, United States Navy, Naval Hydrographic Office.
 C. M. Young, Assistant Secretary of Commerce for Aeronautics.

FUNCTIONS

The functions of the committee on problems of air navigation are as follows:

1. To determine the problems in the field of air navigation that are most important for investigation by governmental and private agencies.

2. To coordinate by counsel and suggestion the research work involved in the investigation of approved problems.

3. To act as a medium for the interchange of information regarding investigations and developments in air navigation, in progress or proposed.

4. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

In order to cover effectively the large and varied field of research and development on problems of air navigation, subcommittees on problems of communication, on instruments, and on meteorological problems were organized under the committee on problems of air navigation. During the past year, however, in connection with a general reorganization of its subcommittees by the executive committee, the subcommittee on problems of communication was discharged on account of the overlapping of its functions with the functions of the liaison committee on aeronautic radio research which had recently been established by the aeronautics branch of the Department of Commerce. The final recommendation of the subcommittee on problems of communication, for the investigation of the transmission characteristics of the radio medium between aircraft and the ground and between aircraft in flight, was referred to the liaison committee on aeronautic radio research, and this problem, as well as other problems in connection with aircraft communications, is being included in the work of the liaison committee.

SUBCOMMITTEE ON INSTRUMENTS

The subcommittee on instruments is at present organized as follows:

Dr. L. J. Briggs, Bureau of Standards, chairman.
 Marshall S. Boggs, aeronautics branch, Department of Commerce.
 Dr. W. G. Brombacher, Bureau of Standards.
 C. H. Colvin, Society of Automotive Engineers.
 Lieut. A. F. Hegenberger, United States Army, matériel division, Air Corps, Wright Field.
 Dr. A. W. Hull, General Electric Co.
 Carl W. Keuffel, Keuffel & Esser.
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
 Lieut. C. D. McAllister, United States Army, matériel division, Air Corps, Wright Field.
 H. J. E. Reid, National Advisory Committee for Aeronautics.
 Lieut. L. D. Webb, United States Navy, Bureau of Aeronautics, Navy Department.

Investigations on the development of instruments for air navigation conducted under the cognizance of the committee on aerodynamics are outlined in the report of that committee. In addition to these investigations a great deal of progress has been made by organizations, which are in the main represented on the subcommittee on instruments, relating to a number of problems listed in the subcommittee's report on the Present Status of Aircraft Instruments (Technical Report No. 371), and certain other navigation problems. A number of these which appear to be outstanding will be briefly considered.

Vibration of instrument panels.—An instrument was developed by the Pioneer Instrument Co. for optically recording the frequency and amplitude of vibration of aircraft instrument panels. It is of such size and weight that it can be substituted for almost any of the instruments with 2.75-inch dial. Results of tests made on 10 airplanes indicate (1) that the frequency of vibration of the instrument panel is the same as the engine speed, (2) that the average amplitude (maximum displacement from equilibrium position) is 0.006 inch, and (3) that the direction of vibration is in general at right angles to the plane of the panel. This confirms the assumptions made in selecting the frequency of the standard vibration used for testing instruments and also shows that the amplitude selected is sufficiently severe. With some additions, these data will furnish a basis on which to set limits to the amplitude of vibration which an instrument should be expected to withstand in service.

Improvements in gyro-instruments.—Airplane operators and testing laboratories have had further experience with the Sperry artificial horizon and directional gyro. In order to obtain satisfactory service from these instruments it appears that greater attention must be given to the control of the operating suction. At present the instruments are operated by Venturi tubes which develop a suction that is dependent both on air speed and altitude. Each gyro-instrument now has its own Venturi tube. It is rather generally believed that the solution of the problem is a mechanically operated pump, which is under development by a number of organizations.

Determination of position.—The instruments and methods for determining the position of aircraft by astronomical observations have been further improved with a view to reducing the time and effort now necessary to obtain a line of position. The Hydrographic Office of the Navy has published a volume entitled "Position Tables for Aerial and Service Navigation" (H. O. No. 209), which may be preferred to the now widely used Navigation Tables for Mariners and Aviators (H. O. No. 208). A new type of sextant, which

is simple in design and comparatively light in weight, has been developed for the Bureau of Aeronautics of the Navy and is now commercially available. Improvements in the watches and methods of determining time have been effected.

Radio aids to navigation.—An extensive program of research on radio aids to navigation is being conducted by the aeronautics branch of the Department of Commerce through its research division at the Bureau of Standards. The development of a radio system as a guide in making landings during fog has formed a large part of the program during the past year, and efforts have centered on the simplification of the indicators to be observed by the pilot. The perfecting of the visual indicator for the directive radio beacon has continued and has included the development of an indicator of the pointer type.

Simplification of indicators.—The space on the instrument panel is limited. Instruments, many of them essential, continue to multiply as the interest and skill in instrument flying increases. It is humanly impossible to observe and coordinate all of the large number of instruments which are now required for instrument flying, instrument landing, and for special purposes. This has led to continual and widespread study of the best possible grouping of the instruments on the panel and of the possibility of eliminating or combining instruments so as to reduce the total number. Thus, during the past year, a combined turn meter and inductor compass was developed commercially, with which it is hoped to eliminate the dial of the turn indicator from the instrument board. Progress is being made in substituting a sensitive altimeter for the customary altimeter and rate-of-climb indicator. An instrument recently adopted as an Army-Navy standard, in which the mechanism of the fuel and oil pressure gauges and the engine thermometer are installed in a single case with a 2.75-inch dial and with separate scales and pointers, is now being made on a commercial scale for the Army Air Corps. It has been the common practice on outboard motors to have the engine instruments mounted on a strut adjacent to the engines, but suitable electrical pressure gauges, thermometers, and tachometers have recently become available so that the indicators can now be conveniently installed on the instrument panel.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The membership of the subcommittee on meteorological problems is as follows:

Prof. Charles F. Marvin, Weather Bureau, chairman.

W. R. Gregg, Weather Bureau.

Dr. W. J. Humphreys, Weather Bureau.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lieut. F. W. Reichelderfer, United States Navy, Naval Air Station, Lakehurst.
Dr. C. G. Rossby, Massachusetts Institute of Technology.
Eugene Sibley, aeronautics branch, Department of Commerce.
Capt. Bertram J. Sherry, United States Army, Signal Corps, War Department.

The principal agency engaged in the study of meteorological problems as related to air navigation is the Weather Bureau. However, practically every organization concerned with the operation of aircraft is interested in problems of this nature, and studies along this line have been conducted by the Signal Corps and Air Corps of the Army and the Bureau of Aeronautics of the Navy in connection with the operation of aircraft.

The work of this subcommittee during the past year was concerned chiefly with problems connected with the navigation of lighter-than-air craft, although some of them apply, in a measure, to heavier-than-air craft also.

Wind gustiness.—The subject that received most attention was that of wind gustiness. At a meeting of the subcommittee held in Washington on January 10, 1931, reports were submitted giving the results of investigations of this problem that had been carried on for more than a year at the Weather Bureau in Washington and at the Lakehurst Naval Air Station. This meeting was held jointly with the subcommittee on airships of the committee on aerodynamics. The reports showed that considerable data have been accumulated and in part analyzed, but that the application of the results to the problems of airship mooring,

docking, and navigation is difficult. The discussion at the joint meeting of the two subcommittees was helpful in that each group was thus enabled to visualize more clearly than before the problems of the other and, therefore, to approach them with a more definite line of attack. In this connection it was announced that the Weather Bureau had established a station at Akron and that special investigations are being planned there. The location of this station is excellent for the purpose, since it will be possible for studies to be made jointly by meteorologists and airship designers.

Announcement was made also that investigation of the problem will be continued at Lakehurst.

Vertical air currents.—Brief reports were submitted regarding investigations of vertical air currents by the Bureau of Aeronautics in connection with glider operation; and in Europe by means of a balloon and two theodolites.

Meteorological surveys related to transatlantic flying.—Reports were made concerning two fairly exhaustive studies on this general subject that have been made during the past year by the Goodyear-Zeppelin Corporation, in cooperation with the Weather Bureau. The purpose of one was to determine the probable average annual number of trips that could be made on schedule each way across the Atlantic by airship; the average time required; and the probable number of delayed and canceled trips. This study was based on a 5-year series of ocean weather maps.

The purpose of the other study was to determine the best site, meteorologically, for a commercial airship base on the North to Middle Atlantic seaboard. This study is being continued. It is based in part on several years' data, already available, and in part on special local data now being secured at the precise locations under consideration. It is expected that this survey will be completed within the next year.

PART IV

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics has issued technical publications during the past year covering a wide range of subjects. There are four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics carried on in different laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aerodynamical laboratory at the Washington Navy Yard, the Bureau of Standards, the Weather Bureau, Stanford University, and the Massachusetts Institute of Technology. In all cases the reports were recommended for publication by the technical subcommittees having cognizance of the investigations. During the past year 39 technical reports were submitted for publication.

Technical notes present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The committee has issued during the past year, in mimeographed form, 44 technical notes.

Technical memorandums contain translations and reproductions of important foreign aeronautical articles of a miscellaneous character. A total of 55 technical memorandums was issued during the past year.

Aircraft circulars contain translations or reproductions of articles descriptive of new types of foreign aircraft. During the past year 25 aircraft circulars were issued.

Summaries of the 39 technical reports and lists of the technical notes, technical memorandums, and aircraft circulars follow:

SUMMARIES OF TECHNICAL REPORTS

The First Annual Report of the National Advisory Committee for Aeronautics for the fiscal year 1915 contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; the twelfth annual report, Nos. 233 to 256; the thirteenth annual report, Nos. 257 to

282; the fourteenth annual report, Nos. 283 to 308; the fifteenth annual report, Nos. 309 to 336; the sixteenth annual report, Nos. 337 to 364; and since the preparation of the sixteenth annual report for the year 1930 the committee has authorized the publication of the following technical reports, Nos. 365 to 400:

Report No. 365, entitled "Aerodynamic Characteristics of Circular-Arc Airfoils at High Speeds," by L. J. Briggs and H. L. Dryden, Bureau of Standards.

The aerodynamic characteristics of eight circular-arc airfoils at speeds of 0.5, 0.65, 0.8, 0.95, and 1.08 times the speed of sound have been determined in an open-jet-air stream 2 inches in diameter, using models of 1-inch chord. The lower surface of each airfoil was plane; the upper surface was cylindrical. As compared with the measurements described in N. A. C. A. Technical Report No. 319 (reference 1), the circular-arc airfoils at speeds of 0.95 and 1.08 times the speed of sound are more efficient than airfoils of the R. A. F. or Clark Y families. At a speed of 0.5 times the speed of sound, the thick circular-arc sections are extremely inefficient, but thin sections compare favorably with those of the R. A. F. family. A moderate rounding of the sharp edges changes the characteristics very little and is in many instances beneficial. The results indicate that the section of the blades of propellers intended for use at high tip speeds should be of the circular-arc form for the outer part of the blade and should be changed gradually to the R. A. F. or Clark Y form as the hub is approached.

Report No. 366, entitled "Dynamic and Flight Tests on Rubber-Cord and Oleo-Rubber-Disk Landing Gears for an *F6C-4* Airplane," by William C. Peck, National Advisory Committee for Aeronautics.

The investigation described in this report was conducted for the purpose of comparing an oleo-rubber-disk and a rubber-cord landing gear, built for use on an *F6C-4* airplane. The investigation consisted of drop tests under various loading conditions and flight tests on an *F6C-4* airplane. In the drop tests the total work done on each gear and the work done on each of the shock-absorbing units were determined. For both drop tests and flight tests the maximum loads and accelerations were determined.

The comparative results showed that the oleo gear was slightly superior in reducing the ordinary landing shocks, that it had a greater capacity for work, and that it was very superior in the reduction of the rebound. The results further showed that for drops comparable to very severe landings, the rubber-cord gear was potentially more effective as a shock-reducing mechanism. However, due to the construction of this chassis, which limited the maximum elongation of the cords, this gear was incapable of withstanding as severe tests as the oleo gear. The action of the oleo gear during the tests was greatly inferior to the action of an ideal gear. The maximum accelerations encountered during the flight tests for severe landings were 3.64g for the rubber-cord gear and 2.27g for the oleo gear. These were less than those experienced in free drops of 7 inches on either gear.

Report No. 367, entitled "Pressure Distribution Over a Thick, Tapered and Twisted Monoplane Wing Model—N. A. C. A. 81-J," by Carl J. Wenzinger, National Advisory Committee for Aeronautics.

This report presents the results of pressure distribution tests on a thick, tapered and twisted monoplane wing model. The investigation was conducted for the purpose of obtaining data on the aerodynamic characteristics of the new wing and to provide additional information suitable for use in the design of tapered cantilever wings. The tests included angles of attack up to 90° and were made in the committee's 5-foot atmospheric wind tunnel.

The span loading over the wing was approximately of elliptical shape, which gave rise to relatively small bending moments about the root. The angle of zero lift for all sections along the span varied only within $\pm 0.4^\circ$ of the angle of zero lift for the whole wing, resulting in small leading edge loads for the high-speed condition of flight. The results also add to the available information for the study of stability at large angles of attack.

Report No. 368, entitled "A New Chart for Estimating the Absolute Ceiling of an Airplane," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.

This report is concerned with the derivation of a chart for estimating the absolute ceiling of an airplane. This chart may be used in conjunction with the usual curves of power required and power available as an accurate substitute for extended calculation, or it may be used in the estimation of absolute ceiling when power curves are not available.

Report No. 369, entitled "Maneuverability Investigation of the F6C-3 Airplane with Special Flight Instruments," by C. H. Dearborn and H. W. Kirschbaum, National Advisory Committee for Aeronautics.

This investigation was made for the purpose of obtaining information on the maneuverability of the F6C-3 fighter airplane. It is the first in a series of similar investigations under way on a number of military airplanes for the purpose of comparing the abilities of these airplanes to maneuver, and also to establish a fund of quantitative data which may be used in formulating standards of comparison for rating the maneuverability of any airplane. A large part of this initial investigation was necessarily devoted to the development and trial of methods suitable for use in subsequent investigations of this nature.

Air speed, angular velocity, linear acceleration, and position of the control surfaces were measured by instruments in the airplane during loops, push-downs, pull-outs from dives, pull-ups from level flight, barrel rolls, and spins. The coordinates of the flight paths were deduced from the data whenever possible, and were checked in some cases by the use of a camera obscura. The results are given in curves showing the variation of the measured quantities with respect to time, and maximum values are tabulated.

Report No. 370, entitled, "Effect of Variation of Chord and Span of Ailerons on Hinge Moments at Several Angles of Pitch," by B. H. Monish, Bureau of Standards.

This report presents the results of an investigation of the hinge moments of ailerons of various chords and spans of two airfoils having the Clark Y and U. S. A. 27 wing sections, supplementing the investigations described in references 1 and 2, of the rolling and yawing moments due to similar ailerons on these two airfoil sections.

The measurements were made at various angles of pitch, but at zero angle of roll and yaw, the wing chord being set at an angle of $+4^\circ$ to the fuselage axis. In the case of the Clark Y airfoil the measurements have been extended to a pitch angle of 40° , using ailerons of span equal to 67 per cent of the wing semispan and chord equal to 20 and 30 per cent of the wing chord.

The work was done in the 10-foot tunnel of the Bureau of Standards on models of 60-inch span and 10-inch chord, having square tips, no taper in plan form or thickness, zero dihedral, and zero sweepback.

Report No. 371, entitled "Present Status of Aircraft Instruments," prepared by subcommittee on instruments, National Advisory Committee for Aeronautics.

This report gives a brief description of the present state of development and of the performance characteristics of the instruments included in the following group:

1. Speed instruments.
2. Altitude instruments.

3. Navigation instruments.
4. Power-plant instruments.
5. Oxygen instruments.
6. Instruments for aerial photography.
7. Fog-flying instruments.
8. General problems.
9. Summary of instrument and research problems. The items considered under performance include sensitivity (associated with aircraft needs), scale errors, effects of temperature and pressure, effects of acceleration and vibration, time lag, damping, leaks, elastic defects, and friction. The viewpoint will be that of the maximum demand which may be made on the instruments. Where possible the trend of present development work will be given.

Report No. 372, entitled "The Gaseous Explosive Reaction—the Effect of Pressure on the Rate of Propagation of the Reaction Zone and upon the Rate of Molecular Transformation," by F. W. Stevens, Bureau of Standards.

A study of the gaseous explosive reaction, the source of power in gas engines, has been in progress at the Bureau of Standards for a number of years as one of the projects undertaken at the request of the National Advisory Committee for Aeronautics. In a recent report on this work, the effect of pressure on the rate of propagation of the explosive-reaction zone and on the rate of energy liberation during the progress of the reaction is considered from a physico-chemical standpoint. The extensive experimental data on which the report is based are drawn from the explosive reaction of a large number of fuels, covering reaction orders from 3 to 15. During their reaction these fuels were subjected to wide ranges of pressure and of other physical conditions usually imposed on the reaction by its industrial applications.

As a result of these studies, there have been brought out a number of important fundamental characteristics of the explosive reaction indicating that the basal processes of the transformation are much simpler and correspond more closely to the general laws and principles of ordinary transformations than is usually supposed.

Perhaps the most striking indication of the simplicity and uniformity of the reaction processes occurring in the explosive transformation is shown in those cases where it is so conditioned that it may run its course at a constant pressure. Under this condition the zone of explosive reaction, initiated at the point of ignition, assumes the form of a sphere, expanding somewhat as a sound wave, within the explosive gases at a uniform rate. This constant linear rate at which the zone is observed to expand in space is not, however, the rate

at which it propagates itself within the gases, thus effecting their transformation. This is because the gases themselves are also in movement outward from the point of ignition. The observed rate of displacement in space of the reaction zone has usually been mistaken for its rate of propagation relative to the gases. The report makes the necessary distinction and shows that the rate of propagation of the zone relative to the gases is independent of the mass movement of the gases. It is further shown that its rate of propagation relative to the gases is independent of the pressure to which they were subjected and that, as a consequence, the rate of molecular transformation within the zone of explosive reaction is proportional to pressure. The report also calls attention to the point that if these simple results are interpreted in the light of a statistical theory of impacts it would mean, since the rate of molecular transformation within the zone was found in all cases to be proportional to pressure, that the transformation within the zone is the result of binary impacts. This result is of unusual interest in the case of the reaction of heavy hydrocarbon fuels and the reaction mechanism proposed by the recent kinetic theory of chain reactions.

Report No. 373, entitled "Coefficients of Discharge of Fuel Injection Nozzles for Compression-Ignition Engines," by A. G. Gelalles, National Advisory Committee for Aeronautics.

This report presents the results of an investigation to determine the coefficients of discharge of nozzles with small, round orifices of the sizes used with high-speed compression-ignition engines. The injection pressures and chamber back pressures employed were comparable to those existing in compression-ignition engines during injection. The construction of the nozzles was varied to determine the effect of the nozzle design on the coefficient. Tests were also made with the nozzles assembled in an automatic injection valve, both with a plain and with a helically grooved stem.

It was found that a smooth passage before the orifice is requisite for high flow efficiency. A beveled leading edge before the orifice gave a higher coefficient of discharge than a rounded edge. Varying the length-diameter ratio from 1 to 3 for one of the orifices having a beveled leading edge was found to have no effect on the value of the coefficient. The results with the nozzles assembled in an automatic injection valve having a plain stem duplicated those with the nozzles assembled at the end of a straight tube of constant diameter. Lower coefficients were obtained with the nozzles assembled in an injection valve having a helically grooved stem.

When the coefficients of nozzles of any one geometrical shape were plotted against values of corresponding Reynolds Numbers for the orifice diameters and

rates of flow tested, it was found that experimental points were distributed along a single curve.

Report No. 374, entitled "The Automotive Ignition Coil," by T. H. Darnell.

This report gives the results of an extensive series of measurements on the secondary voltage induced in an ignition coil of typical construction under a variety of operating conditions. These results show that the theoretical predictions hitherto made as to the behavior of this type of apparatus are in satisfactory agreement with the observed facts. The large mass of data obtained is here published both for the use of other investigators who may wish to compare them with other theoretical predictions and for the use of automotive engineers who will here find definite experimental results showing the effect of secondary capacity and resistance on the crest voltage produced by ignition apparatus.

Report No. 375, entitled "Full-Scale Tests of Metal Propellers at High Tip Speeds," by Donald H. Wood, National Advisory Committee for Aeronautics.

This report describes tests of 10 full-scale metal propellers of several thickness ratios at various tip speeds up to 1,350 feet per second. The tests were made in the Committee's 20-foot propeller research tunnel.

The results indicate no loss of efficiency up to tip speeds of approximately 1,000 feet per second. Above this tip speed the loss is at a rate of about 10 per cent per 100 feet per second increase relative to the efficiency at the lower speeds for propellers of pitch diameter ratios 0.3 to 0.4. Propellers having sections of small thickness ratio can be run at slightly higher speeds than thick ones before beginning to lose efficiency.

Report No. 376, entitled "Some Approximate Equations for the Standard Atmosphere," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.

This report contains the derivation of a series of simple approximate equations for density ratios $\frac{\rho}{\rho_0}$, $\frac{p}{p_0}$, $\sqrt{\frac{p_0}{\rho}}$ and for the pressure ratio $\frac{p}{p_0}$ in the standard atmosphere. The accuracy of the various equations is discussed and the limits of applications are given. Several of these equations are in excellent agreement with the standard values.

Report No. 377, entitled "A Method of Flight Measurement of Spins," by Hartley A. Soulé and Nathan F. Scudder, National Advisory Committee for Aeronautics.

A method is described involving the use of recording turn meters and accelerometers and a sensitive

altimeter, by means of which all of the physical quantities necessary for the complete determination of the flight path, motion, attitude, forces, and couples of a fully developed spin can be obtained in flight. Data are given for several spins of two training type airplanes which indicate that the accuracy of the results obtained with the method is satisfactory.

The method was developed by the National Advisory Committee for Aeronautics, as a part of a general study of the phenomenon of spinning. It is now being used in an investigation to determine how the spinning characteristics of several airplanes are affected by various changes in their inertia and geometric characteristics. A study is being made to extend the method to include measurements during the entry and recovery from a spin as well as during the fully developed spin.

Report No. 378, entitled "Comparison of Full-Scale Propellers Having R. A. F. 6 and Clark Y Airfoil Sections," by Hugh B. Freeman, National Advisory Committee for Aeronautics.

In this report the efficiencies of two series of propellers having two types of blade sections are compared. Six full-scale propellers were used, three having R. A. F. 6 and three Clark Y airfoil sections with thickness/chord ratios of 0.06, 0.08, and 0.10. The propellers were tested at five pitch settings, which covered the range ordinarily used in practice. These tests were conducted in the committee's 20-foot propeller research tunnel.

The propellers having the Clark Y sections gave the highest peak efficiency at the low pitch settings. At the higher pitch settings, the propellers with the R. A. F. 6 sections gave about the same maximum efficiency as the Clark Y propellers and were more efficient for the conditions of climb and take-off.

Report No. 379, entitled "Rolling Moments Due to Rolling and Yaw for Four Wing Models in Rotation," by Montgomery Knight and Carl J. Wenzinger, National Advisory Committee for Aeronautics.

This report presents the results of a series of autorotation and torque tests on four different rotating wing systems at various rates of roll and at several angles of yaw. The investigation covered an angle-of-attack range up to 90° and angles of yaw of 0°, 5°, 10°, and 20°. The tests were made in the committee's 5-foot, closed-throat atmospheric wind tunnel. The object of the tests was primarily to determine the effects of various angles of yaw on the rolling moments of the rotating wings up to large angles of attack.

It was found that at angles of attack above that of maximum lift the rolling moments on the wings due to yaw (or side slip) from 5° to 20° were roughly of

the same magnitude as those due to rolling. There was a wide variation in magnitude of the rolling moment due to yaw angle with both angle of attack and with $\frac{pb}{2V}$. The rates and ranges of stable autorotation for the monoplane models were considerably increased by yaw, whereas for an unstaggered biplane they were little affected. The immediate cause of the rolling moment due to yaw is apparently the building up of large loads on the forward wing tip and the reduction of loads on the rearward wing tip.

Report No. 380, entitled "Pressure Distribution over the Fuselage of a PW-9 Pursuit Airplane in Flight", by Richard V. Rhode and Eugene E. Lundquist, National Advisory Committee for Aeronautics.

This report presents the results obtained from pressure distribution tests on the fuselage of a PW-9 pursuit airplane in a number of conditions of flight. The investigation was made to determine the contribution of the fuselage to the total lift in conditions considered critical for the wing structure, and also to determine whether the fuselage loads acting simultaneously with the maximum tail loads were of such a character as to be of concern with respect to the structural design of other parts of the airplane.

The results show that the contribution of the fuselage toward the total lift is small on this airplane, ranging from slightly less than 3 per cent at the lower angles of attack to about 4 per cent at the higher angles, which approximately compensates for the portion of the wing area replaced by the fuselage. Aerodynamic loads on the fuselage are, in general, unimportant from the structural viewpoint, and in most cases they are of such character that, if neglected, a conservative design results. In spins, aerodynamic forces on the fuselage produce diving moments of appreciable magnitude and yawing moments of small magnitude, but opposing the rotation of the airplane.

A table of cowling pressures for various maneuvers is included in the report.

Report No. 381, entitled "Static, Drop, and Flight Tests on Musselman Type Airwheels," by William C. Peck and Albert P. Beard, National Advisory Committee for Aeronautics.

The investigation described in this report was conducted for the purpose of obtaining quantitative information on the shock-reducing and energy-dissipating qualities of a set of 30 by 13-6 Musselman type airwheels. The investigation consisted of static, drop, and flight tests. The static tests were made with inflation pressures of approximately 0, 5, 10, 15, 20, and 25 pounds per square inch and loadings up to 9,600 pounds. The drop tests were made with inflation pressures of approximately 5, 10, 15, 20, and 25

pounds per square inch and loadings of 1,840, 2,440, 3,050, and 3,585 pounds. The flight tests were made with a VE-7 airplane weighing 2,153 pounds, with the tires inflated to 5, 10, and 15 pounds per square inch. The landing gears used in conjunction with the airwheels were practically rigid structures.

The results of the tests showed that the walls of the tires carried a considerable portion of the load, each tire supporting a load of 600 pounds with a depression of approximately 6 inches.

The shock-reducing qualities, under severe tests, and the energy-dissipating characteristics of the tires, under all tests, were poor. The latter was evidenced by the rebound present in all landings made. In the severe drop tests the free rebound reached as much as 60 per cent of the free drop.

The results indicate that a shock-reducing and energy-dissipating mechanism should be used in conjunction with airwheels.

Report No. 382, entitled "Elastic Instability of Members Having Sections Common in Aircraft Construction," by George W. Trayer and H. W. March, Forest Products Laboratory.

Two fundamental problems of elastic stability are discussed in this report. In Part I formulas are given for calculating the critical stress at which a thin, outstanding flange of a compression member will either wrinkle into several waves or form into a single half wave and twist the member about its longitudinal axis. A mathematical study of the problem, which together with experimental work has led to these formulas, is given in an appendix. Results of tests substantiating the recommended formulas are also presented. In Part II the lateral buckling of beams is discussed. The results of a number of mathematical studies of this phenomenon have been published prior to this writing, but very little experimentally determined information relating to the problem has been available heretofore. Experimental verification of the mathematical deductions is supplied in this report.

Report No. 383, entitled "On the Theory of Wing Sections With Particular Reference to the Lift Distribution," by Theodore Theodorsen, National Advisory Committee for Aeronautics.

This report describes a simple and exact method of calculating the lift distribution on thin wing sections. The most essential feature of the new theory is the introduction of an "ideal angle of attack," this angle being defined as that at which the flow enters the leading edge smoothly or, more precisely, as the angle of attack at which the lift at the leading edge equals zero. The lift distribution at this particular angle is shown to be a characteristic property

of the section and has been termed the "basic distribution." It is shown that the lift of a wing section may always be considered to consist of (a) the basic distribution and (b) the additional distribution, where the latter is independent of the mean camber line and thus identical for all thin sections. The specific reason for the poor aerodynamic qualities of thin wing sections is pointed out as being due to the fact that the additional lift in potential flow becomes infinite at the leading edge.

The theory is in consequence adapted to describe some of the properties of actual wing sections. It is established that the essential parameter occurring in this analysis is the radius of curvature at the leading edge. The location and magnitude of the maximum lift intensity is determined. It is further pointed out that the actual slope of the lift curve is dependent on this parameter.

The theoretical lift distribution is compared with the distribution obtained by direct measurement on a number of the more conventional wing sections. The results check satisfactorily and may be considered as a confirmation of the validity of the theory.

The new theory will be of value in the further improvements of airplane wings. It is pointed out that airplanes should be operated near the ideal angle of attack. The theory will also be of use in calculating the structural strength of wing sections.

Report No. 384, entitled "The Comparative Performance of Superchargers," by Oscar W. Schey, National Advisory Committee for Aeronautics.

This report presents a comparison of superchargers on the basis of the power required to compress the air at a definite rate, and on the basis of the net engine power developed at altitudes from 0 to 40,000 feet. The investigation included geared centrifugal, turbine-driven centrifugal, Roots, and vane-type superchargers. It also includes a brief discussion of the mechanical limitations of each supercharger and explains how the method of control affects the power requirements.

The results of this investigation show that for critical altitudes below 20,000 feet there is a maximum difference of about 6 per cent between the amounts of net engine power developed by the various types of superchargers when ideal methods of control are employed, but for critical altitudes above 20,000 feet an engine develops considerably more power when equipped with a turbocentrifugal supercharger than with any other type. The Roots type gives the lowest net engine power of all at high critical altitudes, because it has the least efficient type of compression.

The throttling method of control used on the geared-centrifugal type of supercharger is very unsatisfactory at low altitudes from a net engine-power stand-

point when compared with the method used on the Roots or turbocentrifugal type.

Report No. 385, entitled "Wind Tunnel Tests on Airfoil Boundary Layer Control Using a Backward-Opening Slot," by Millard J. Bamber, National Advisory Committee for Aeronautics.

This report presents the results of an investigation to determine the effect of boundary layer control on the lift and drag of an airfoil. Boundary layer control was accomplished by means of a backward-opening slot in the upper surface of the hollow airfoil. Air was caused to flow through this slot by a pressure which was maintained inside the airfoil by a blower. Various slot locations, slot openings, and wing pressures were used. The tests were conducted in the committee's 5-foot atmospheric wind tunnel.

The quantity of air flowing through the slot per unit time was measured and is presented in coefficient form. A coefficient is derived from which the power required to maintain the air flow through the slot may be computed.

The effect of each variable is illustrated by characteristic curves. A discussion indicating the advantages which might be possible by the application of boundary layer control to an airplane is included.

A discussion of the various forces produced on the airfoil by this type of boundary layer control and their resultants is given in Appendix I.

Under the test conditions, the maximum lift coefficient was increased about 96 per cent for one slot arrangement and the minimum drag coefficient was decreased about 27 per cent for another, both being compared with the results obtained with the unslotted airfoil. It is believed from the results of this investigation that the above effects may be increased by the use of larger slot openings, better slot locations, multiple slots, improved airfoil profiles, and trailing edge flaps.

Report No. 386, entitled "Maneuverability Investigation of an F6C-4 Fighting Airplane," by C. H. Dearborn and H. W. Kirschbaum, National Advisory Committee for Aeronautics.

In order to compare the relative maneuverability of two fighting airplanes and to accumulate additional data to assist in establishing a satisfactory criterion for the maneuverability of any airplane, the National Advisory Committee for Aeronautics, at the request of the Bureau of Aeronautics, Navy Department, has conducted maneuverability investigations on the F6C-3 (water-cooled engine) and the F6C-4 (air-cooled engine) airplanes. The investigation made on the F6C-3 airplane has been previously reported. This report contains the results of the investigation made on the F6C-4 airplane.

Measurements of air speed, angular velocity, linear acceleration, temperature, pressure, and the position of the controls were made for practically all the kinds of military maneuvers required of this type of airplane. Flight path coordinates were secured for most of the maneuvers by means of a special camera obscura developed for this investigation. The results are given in the form of curves, some showing the variation of the measured quantities with respect to time; others, the variation of some maximum quantities with respect to air speed. In addition, all maximum quantities are tabulated.

A comparison of the results with those obtained in the investigation conducted on the *F6C-3* airplane shows that: With practically the same speed and control movement, the *F6C-4* completed a loop in 10 per cent less time than did the *F6C-3*; in dives the *F6C-3* increased its speed more rapidly than did the *F6C-4*; and the minimum radius of turn was found to be 135 feet at 61.5 miles per hour for the *F6C-4*, and 155 feet at 76 miles per hour for the *F6C-3*.

Report No. 387, entitled "The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics," by Carl J. Wenzinger and Thomas A. Harris, National Advisory Committee for Aeronautics.

The vertical open-throat wind tunnel of the committee is described in this report. The tunnel was built mainly for studying the spinning characteristics of airplane models, but may be used as well for the usual types of wind-tunnel tests. A special spinning balance is being developed to measure the desired forces and moments with the model simulating the actual spin of an airplane.

Satisfactory air flow has been attained with a velocity that is uniform over the jet to within ± 0.5 per cent. The turbulence present in the tunnel has been compared with that of several other tunnels by means of the results of sphere drag tests and was found to average well with the values of those tunnels. Included also in the report are comparisons of results of stable autorotation and of rolling-moment tests obtained both in the vertical tunnel and in the old horizontal 5-foot atmospheric tunnel.

Report No. 388, entitled "Investigation of the Diaphragm-Type Pressure Cell," by Theodore Theodorsen, National Advisory Committee for Aeronautics.

This report relates to various improvements in the process of manufacture of the N. A. C. A. standard pressure cell. Like most pressure-recording devices employing thin diaphragms, they would in general show considerable change in calibration with temperature and also some change of calibration with time or aging effect. Some instruments exhibited considerable internal friction.

It was established that the temperature dependency of the stiffness was due to difference in the thermal expansivity between the diaphragm proper and the supporting body of the cell, and convenient methods for its compensation have been developed. The diaphragm is furnished with a small central bushing of a different metal, and it is possible to determine a size of this bushing which gives the diaphragm exactly the same thermal expansivity as the cell body.

It was further established that the internal hysteresis in the diaphragm was of a negligible magnitude and that the observed lag was due, primarily, to the force of the hairspring on the stylus point. The resultant adoption of weaker hairsprings made it possible to extend the useful range of the instrument considerably downward. Satisfactory instruments having a range of less than 3 inches of water were made possible.

It was found that the tendency to change calibration with time was caused, to a great extent, by insufficient clamping of the diaphragm. The adoption of double copper gaskets improved this condition.

The required diaphragm thickness and the desirable rate of mechanical magnification have been determined on the basis of several hundred tests.

Report No. 389, entitled "The Effect of Small Angles of Yaw and Pitch on the Characteristics of Airplane Propellers," by Hugh B. Freeman, National Advisory Committee for Aeronautics.

The tests described in this report were carried out in the committee's 20-foot propeller research tunnel to determine the effect on the characteristics of a propeller of inclining the propeller axis at small angles to the relative wind. Tests were made of a full-scale propeller and fuselage combination at four angles of yaw (0° , $+5^\circ$, $+10^\circ$, and $+15^\circ$), and of a model propeller, nacelle, and wing combination at five angles of pitch (-5° , 0° , $+5^\circ$, $+10^\circ$, and $+15^\circ$).

The results of the full-scale tests of a propeller and fuselage, without a wing, show that the effect on the propeller performance is small. Similar results are shown by the model test data except that where the propeller is directly in front of the wing there is an appreciable decrease in effective thrust and propulsive efficiency with increase of angle of pitch.

Report No. 390, entitled "The Effect of Valve Timing upon the Performance of a Supercharged Engine at Altitude and an Unsupercharged Engine at Sea Level," by Oscar W. Schey and Arnold E. Biermann, National Advisory Committee for Aeronautics.

The investigation described in this report was conducted to determine the comparative effects of valve timing on the performance of an unsupercharged engine at sea level and a supercharged engine at alti-

tude. The tests were conducted on the N. A. C. A. Universal test engine. The timing of the four valve events was varied over a wide range; the engine speeds were varied between 1,050 and 1,500 revolutions per minute; the compression ratios were varied between 4.35:1 and 7.35:1. The conditions of exhaust pressure and carburetor pressure of a supercharged engine were simulated for altitude between 0 and 18,000 feet. The results show that optimum valve timing for a supercharged engine at an altitude of 18,000 feet differs slightly from that for an unsupercharged engine at sea level. A small increase in power is obtained by using the optimum timing for 18,000 feet for altitudes above 5,000 feet. The timing of the intake opening and exhaust closing becomes more critical as the compression ratio is increased.

Report No. 391, entitled "The Aerodynamic Characteristics of Eight Very Thick Airfoils from Tests in the Variable Density Wind Tunnel," by Eastman N. Jacobs, National Advisory Committee for Aeronautics.

This report describes tests made in the committee's variable-density wind tunnel on a group of eight very thick airfoils having sections of the same thickness as those used near the roots of tapered airfoils. The tests were made to study certain discontinuities in the characteristic curves that have been obtained from previous tests of these airfoils, and to compare the characteristics of the different sections at values of the Reynolds Number comparable with those attained in flight. The discontinuities were found to disappear as the Reynolds Number was increased. The results obtained from the large-scale tests in this series indicate that the N. A. C. A. 0021 airfoil, a symmetrical airfoil having a thickness ratio of 21 per cent, has the best general characteristics.

Report No. 392, entitled "Reduction of Turbulence in Wind Tunnels," by Hugh L. Dryden, Bureau of Standards.

A brief nonmathematical outline is given in this report of modern views as to the nature of the effect of turbulence, and their bearing on the desirability of designing wind tunnels for small or large turbulence. Experiments made on a particular wind tunnel for the purpose of reducing the turbulence are described, to illustrate the influence of certain factors on the magnitude of the turbulence. Moderate changes in the size, shape, and wall thickness of cells of the honeycomb were found to have little effect. The addition of a room honeycomb at the entrance was also of little value in reducing the turbulence. The turbulence decreased with increasing distance between the honeycomb and the measuring station. A further decrease was obtained by using a large area reduc-

tion in the entrance cone, with the honeycomb at the extreme entrance end.

The measurements of turbulence were made by the use of spheres and also by the use of the hot wire anemometer as described in reference 5.

Report No. 393, entitled "Span-Load Distribution as a Factor in Stability in Roll," by Montgomery Knight and Richard W. Noyes, National Advisory Committee for Aeronautics.

This report gives the results of pressure-distribution tests made to study the effects on lateral stability of changing the span-load distribution on a rectangular monoplane wing model of fairly thick section. Three methods of changing the distribution were employed: Variation in profile along the span to a thin symmetrical section at the tip, twist from $+5^\circ$ to -15° at the tip, and sweepback from $+20^\circ$ to -20° . The tests were conducted in the committee's 5-foot closed-throat atmospheric wind tunnel.

The rolling moment due to roll at a rate of rotation equivalent to that resulting from the maximum rolling disturbances encountered in normal flight is used as the principal basis of comparison. Normal force curves are given for the purpose of estimating the general effectiveness of each wing arrangement.

The investigation shows the following outstanding results:

1. Change in profile along the span from the N. A. C. A. 84 at the root to the N. A. C. A.-M2 at the tip considerably reduces lateral instability, but also reduces the general effectiveness of the wing.

2. Washout up to 11° progressively reduces maximum lateral instability.

3. Transition from sweepforward to sweepback gradually reduces the useful angle-of-attack range, but has no clearly defined effect on maximum lateral instability.

Report No. 394, entitled "Airship Model Tests in the Variable Density Wind Tunnel," by Ira H. Abbott, National Advisory Committee for Aeronautics.

This report describes an investigation of the aerodynamic characteristics of airship models made in the committee's variable-density wind tunnel. Eight Goodyear-Zeppelin airship models, supplied by the Bureau of Aeronautics of the Navy Department, were tested in the original closed-throat tunnel. After the tunnel was rebuilt with an open throat a new model was tested, and one of the Goodyear-Zeppelin models was retested. These tests were made at tank pressures varying from 1 to 20 atmospheres, and the extreme range of Reynolds Number was about 1,000,000 to 40,000,000. The lift, drag, and moment coefficients of the models were determined, and the effects upon these coefficients of pitch, fineness ratio, scale, surface

texture, initial degree of air-stream turbulence, and the effects of the addition of fins and cars were investigated. The resulting curves are included.

The results show that the addition of fins and car to the bare hull of a model causes an increase in lift at positive angles of pitch and causes an additional drag which increases with the pitch. Little change in drag coefficient was found between a fineness ratio of about five and seven. The effect of surface roughness on drag was found to be very large. The drag coefficient and the apparent effect of scale depend upon the initial degree of air-stream turbulence. The results indicate that much may be done to determine the drag of airships from evaluations of the pressure and skin-frictional drags on models tested at large Reynolds Numbers.

Report No. 395, entitled "A New Principle of Sound-Frequency Analysis," by Theodore Theodorsen, National Advisory Committee for Aeronautics.

In connection with a study of aircraft and propeller noises, the committee has developed an instrument for sound-frequency analysis which differs fundamentally from previous types, and which, owing to its simplicity of principle, construction, and operation, has proved to be of value in the investigation described in this report. The method is based on the well-known fact that the ohmic loss in an electrical resistance is equal to the sum of the losses of the harmonic components of a complex wave, except for the case in which any two components approach or attain vectorial identity, in which case the ohmic loss is increased by a definite amount. This fact has been utilized for the purpose of frequency analysis by applying the unknown complex voltage and a known voltage of pure sine form to a common resistance. By varying the frequency of the latter throughout the range in question, the individual components of the former will manifest themselves, both with respect to intensity as well as frequency, by changes in the temperature of the resistance. This principle of frequency analysis has been presented mathematically and a number of distinct advantages relative to previous methods have been pointed out. Among these is the fact that the frequency discrimination or resolving power is inherently large and remains constant for the entire working range. No difficulties exist as to distortions of any kind. The fidelity of operation depends solely on the quality of the associated vacuum-tube equipment.

An automatic recording instrument embodying this principle is described in detail. It employs a beat-frequency oscillator as a source of variable frequency. A large number of experiments have verified the predicted superiority of the method. A number of representative records are presented.

Report No. 396, entitled "Hydraulics of Fuel Injection Pumps for Compression-Ignition Engines," by A. M. Rothrock, National Advisory Committee for Aeronautics.

In this report formulas are derived for computing the instantaneous pressures delivered by a fuel pump. The first derivation considers the compressibility of the fuel and the second the compressibility, elasticity, and inertia of the fuel. The second derivation follows that given by Sass; it is shown to be the more accurate of the two. Additional formulas are given for determining the resistance losses in the injection tube. Experimental data are presented in support of the analyses. The report is concluded with an application of the theory to the design of fuel-pump injection systems for which sample calculations are included.

Report No. 397, entitled "The Drag Characteristics of Several Airships Determined by Deceleration Tests," by F. L. Thompson and H. W. Kirschbaum, National Advisory Committee for Aeronautics.

The results of deceleration tests conducted for the purpose of determining the drag characteristics of six airships are given in this report. The tests were made during the past few years with airships of various shapes and sizes belonging to the Army, the Navy, and the Goodyear-Zeppelin Corporation. In each instance the agency owning the airship cooperated with the National Advisory Committee for Aeronautics in conducting the tests. Although the deceleration tests with the U. S. S. *Los Angeles* have been previously reported, the final results obtained with that airship are included in this report for comparison.

Drag coefficients for the following airships are shown: Army *TC-6*, *TC-10*, and *TE-2*; Navy *Los Angeles* and *ZMC-2*; Goodyear *Puritan*. The coefficients vary from about 0.045 for the small blunt airships to 0.023 for the relatively large slender *Los Angeles*. This variation may be due to a combination of effects, but the most important of these is probably the effect of length-diameter ratio.

Report No. 398, entitled "Investigation of Damping Liquids for Aircraft Instruments—II," by M. R. Houseman and G. H. Keulegan, Bureau of Standards.

This report presents data on the kinematic viscosity in the temperature range -50° to $+30^{\circ}$ C., of pure liquids and of solutions of animal oils, vegetable oils, mineral oils, glycerine, and ethylene glycol in various low freezing point solvents. It is shown that the thermal coefficient of kinematic viscosity as a function of the kinematic viscosity of the solutions of glycerine and ethylene glycol in alcohols is practically inde-

pendent of the temperature and the chemical composition of the individual liquids. This is similarly true for the mineral-oil group and, for a limited temperature interval, for the pure animal and vegetable oils.

The efficiency of β -naphthol, hydroquinone, and diphenylamine to inhibit the change of viscosity of poppyseed and linseed oils was also investigated.

Report No. 399, entitled "Flame Movement and Pressure Development in an Engine Cylinder," by Charles F. Marvin, jr., and Robert D. Best, Bureau of Standards.

The investigation described in this report, which was carried out at the Bureau of Standards at the request of the National Advisory Committee for Aeronautics, presents a visual method for making stroboscopic observations, through a large number of small windows, of the spread of flame throughout the combustion chamber of a gasoline engine. Data, secured by this method on a small engine burning gaseous fuels, are given to show the effects of mixture ratio, spark advance, engine speed, charge density, degree of dilution, compression ratio, and fuel composition on flame movement in the cylinder. Partial indicator diagrams showing pressure development during the combustion period are included. Although present knowledge is not sufficient to permit qualitative evaluation of the separate effects on flame movement of chemical reaction velocity, thermal expansion of burned gases, resonance, turbulence, and piston movement, the qualitative influence of certain of these factors on some of the diagrams is indicated.

Report No. 400, entitled "The Aerodynamic Characteristics of a slotted Clark Y Wing as Affected by the Auxiliary Airfoil Position," by Carl J. Wenzinger and Joseph A. Shortal, National Advisory Committee for Aeronautics.

Aerodynamic force tests on a slotted Clark Y wing described in this report, were conducted in the committee's vertical wind tunnel to determine the best position for a given auxiliary airfoil with respect to the main wing. A systematic series of 100 changes in location of the auxiliary airfoil were made to cover all the probable useful ranges of slot gap, slot width, and slot depth. The results of the investigation may be applied to the design of automatic or controlled slots on wings with geometric characteristics similar to the wing tested.

An increase of 41.5 per cent in the maximum lift above that of the plain wing was obtained for the slotted Clark Y wing. At the same time, the angle of attack for maximum lift was increased 13°. It was found that a maximum increase of about 30° was possible in the highest stalling angle, but at a maximum lift coefficient slightly less than that of the plain

wing. However, with one slot position, an increase of 25°, together with an increase in the maximum lift coefficient of 23.3 per cent, was obtained. The best positions of the auxiliary airfoil were covered by the range of the tests, and the position for desired aerodynamic characteristics may easily be obtained from charts prepared especially for the purpose.

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- | No. | |
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| 351. | An Accurate Method of Measuring the Moments of Inertia of Airplanes. By M. P. Miller. |
| 352. | Effect of Orifice Length-Diameter Ratio on Spray Characteristics. By A. G. Gelalles. |
| 353. | Analytical Determination of the Load on a Trailing Edge Flap. By Robert M. Pinkerton. |
| 354. | An Investigation of the Phenomenon of Separation in the Air Flow Around Simple Quadric Cylinders. By John F. Parsons and Jarvis A. Wallen. |
| 355. | Effect of the Angular Position of the Section of a Ring Cowling on the High Speed of an XF70-1 Airplane. By Melvin N. Gough. |
| 356. | Some Characteristics of Fuel Sprays from Open Nozzles. By A. M. Rothrock and D. W. Lee. |
| 357. | Bending Tests of Metal Monocoque Fuselage Construction. By Ralph W. Mossman and Russell G. Robinson. |
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| 359. | A Balanced Diaphragm Type of Maximum Cylinder Pressure Indicator. By J. A. Spanogle and John H. Collins. |
| 360. | The Pressure Distribution Over a Square Wing Tip on a Biplane in Flight. By Richard V. Rhode and Eugene E. Lundquist. |
| 361. | The Effect of Small Variations in Profile of Airfoils. By Kenneth E. Ward. |
| 362. | Lift and Drag Characteristics of a Cabin Monoplane Determined in Flight. By F. L. Thompson and P. H. Keister. |
| 363. | The Behavior of Conventional Airplanes in Situations Thought to Lead to Most Crashes. By Fred E. Weick. |
| 364. | Tests in the Variable Density Wind Tunnel to Investigate the Effects of Scale and Turbulence on Airfoil Characteristics. By John Stack. |
| 365. | Interference Effects and Drag of Struts on a Monoplane Wing. By Kenneth E. Ward. |
| 366. | Torsion in Box Wings. By John B. Wheatley. |

- No. 367. The Aerodynamic Characteristics of Three Tapered Airfoils Tested in the Variable Density Wind Tunnel. By Raymond F. Anderson.
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BIBLIOGRAPHY OF AERONAUTICS

During the past year the committee issued a bibliography of aeronautics for the year 1929. It had previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, 1922, 1923, 1924, 1925, 1926, 1927, and 1928. A bibliography for the year 1930 is now in the hands of the printer and should be ready for distribution during the coming year. A bibliography is now being published annually by the committee. All issues of the Bibliography of Aeronautics to date were prepared by Paul Brockett.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research.

PART V

SUMMARY OF PROGRESS IN AERONAUTICAL RESEARCH

AERODYNAMICS

From all points of view the progress in aerodynamic development has been gratifying. Work has been done and valuable results obtained on all major lines of research. A better and more general understanding of the fundamental problems of aeronautics and their relative importance has led to a more definite program for study and testing. New equipment is now available for investigation along lines formerly inaccessible. The progress during the past year has been particularly satisfactory.

In any survey of the contributions made by the National Advisory Committee for Aeronautics to aerodynamic development, three general lines of investigation are outstanding in importance. These are the complete justification of the variable-density wind tunnel and its valuable contributions to the knowledge of full-scale air forces; the contributions of the propeller research tunnel to the knowledge of propulsive efficiencies and drag components; and the contributions of the flight-testing program to the knowledge of loads and load distribution in flight. Further extension of existing information and greater refinement of existing theories are demanded for continued progress.

It is the policy of the committee to cooperate closely with the War, Navy, and Commerce Departments and conduct investigations which they request. Most of the problems submitted by these departments are concerned with the immediate needs of air commerce or of the military services. These problems are usually of an urgent nature, and it is the committee's policy to make these studies as parts of general investigations whenever possible, and to extend the work in all cases to cover as much fundamental information as practicable within the limitations of time, personnel, and equipment.

The major problems with which the committee has been concerned may be classified under the general groups of safety in flight, improvements in aerodynamic efficiency, and improvements in design and operation. Many of the problems are studied simultaneously in the wind tunnels and in free flight.

The addition of several items of new equipment has greatly extended the facilities of the committee for conducting certain investigations. The 5-foot vertical

wind tunnel which was completed last year is being equipped with a 6-component spinning balance for fundamental investigations of spinning. A new 7 by 10 foot wind tunnel completed during the past year has been employed on the general investigation of low-speed control. The new 30-by-60-foot full-scale wind tunnel, which was completed in May, 1931, opens an entirely new field in the study of detail design, since full-scale airplanes may be quickly tested for the effects of small structural changes affecting drag or control that are not subject to accurate investigation by other means. It is too soon to appraise the application of this wind tunnel to steady-flight problems, but preliminary tests indicate that it will be of even greater value than originally anticipated.

The N. A. C. A. Tank, which was also completed in May, 1931, has been in operation on the calibration of equipment and on general investigations. The tank has a channel length of 2,020 feet and a carriage speed in excess of 55 miles per hour. With this tank it will be possible to make accurate tests on large-size models of seaplane floats, flying-boat hulls, and other important hydrodynamic problems. Fundamental information of this character is essential to the development of commercial and military seaplanes and of large flying boats.

There follows a brief summary of the work done during the past year and an indication of the most promising lines of investigation to be undertaken in the future.

Spinning.—The airplane spin is still the most important general problem under investigation. During the past year considerable work has been done on various phases of this problem, with definite progress in the matter of preventing involuntary spins near the ground. Repeated tests have shown that an involuntary spin is practically impossible with airplanes which have the elevator control limited to prevent a stall. This work is being continued with a study of landing-gear design made necessary by the limited elevator control.

All phases of the steady spin have been studied in some form either in the wind tunnel or in flight tests. The wind-tunnel work for the greater part has consisted in the measurements of forces and moments on various wing arrangements for a systematic series of angles in pitch and yaw. The flight tests have been

concerned chiefly with the effects of mass distribution. This part of the investigation has been recently completed, with rather surprising results. In neither of two airplanes tested was it possible to produce an uncontrollable spin by any practicable change in mass distribution or balance. This leads to a presumption that most uncontrollable spins are probably due to aerodynamic causes rather than to the inertia effects. The effects of varying the mass distribution and balance have been thoroughly covered and the next step is to apply these data to the calculation of spins from static wind-tunnel tests. The spinning balance in the new 5-foot vertical wind tunnel is expected to prove of great value in the study of the forces under spinning conditions.

While the testing so far completed has indicated that mass distribution is of less importance than was expected, the routine measurement of moments and ellipsoids of inertia has been continued. A report giving these data for 12 types of airplanes has been published.

Various methods of preventing spins or of assisting in the recovery are being considered. Tests being conducted, chiefly in the new 5-foot and the new 7 by 10 foot wind tunnels, cover the effects of various types of slots, plan form of wings, twist of wings, floating ailerons, and differential ailerons. Full-scale tests on promising schemes are to be made from time to time.

Structural loading.—Improvement in structural safety and design efficiency is dependent to a great extent on the knowledge of air loads and load distribution. Lacking exact and complete information, the airplane designer must effect some compromise between safety and excess structural weight. One of the most important services rendered by the committee has been the investigation of loads and load distributions for various service conditions, thus supplying information leading to more exact design rules. During the past year the continuation of work on pull-ups from dives has led to the adoption of new design requirements for various types of military airplanes. This step appears to be of the greatest importance in that for the first time the load factors are being based on rational factors depending on the characteristics of each individual type of airplane.

This investigation is being extended to cover all types of airplanes, including commercial air transports. A special continuously recording combined air-speed indicator and accelerometer has been designed for installation in typical airplanes. This instrument is expected to give definite information on the loads encountered under various conditions of service.

The study of pressure distribution on wing tips of various shapes has been practically completed, with

very satisfactory results. A form of wing tip having a straight-line center-of-pressure locus has been developed and sufficient data are now available to formulate laws of load distribution over wing tips of any conventional shape.

Reduction of drag.—The greatest source of real improvement in airplane efficiency lies in the reduction of all drag components to their minimum values. The possibilities appear very promising along this line. The published work of the National Advisory Committee for Aeronautics on air-cooled-engine cowlings has resulted in an improvement in commercial and military airplane performance, and work now under way on interference drag between nacelles and wings gives promise of additional improvements for multi-engine airplanes. The subject of interference drag is being given special attention in the variable-density and propeller research tunnels. As the data accumulate the importance of this field becomes more evident. The new full-scale wind tunnel will be of valuable assistance in the final stages of this research.

Upon completion of the nacelle-propeller investigation in the propeller research tunnel an extended study of landing-gear resistance is to be made.

Stability and control.—The program of longitudinal-stability tests on a light commercial airplane has been completed and a report covering this work is now being prepared. The next step in this investigation is to study the lateral stability on the same airplane. The purpose of this work is to find some satisfactory method for predicting stability characteristics.

Control at low speeds has received considerable attention as a part of the spinning investigation. Tests have been made in the 7 by 10 foot wind tunnel on a series of ailerons including the differential and floating types. The important findings of this study are being covered by technical reports now in preparation. A continuation of the research is to cover more completely the wing-tip floating-type aileron and the "spoiler" flap.

A number of flight tests have been made with limited elevator control as a part of the spinning investigation. This line of work is being continued with special landing gears, and with an airplane fitted with slots and flaps.

Wind-tunnel pressure-distribution tests on the effects of changing the lift distribution along the span have been completed. A definite reduction of maximum instability in rolling was obtained with either geometric or aerodynamic washout, but sweepback or sweepforward appeared to have no appreciable effect. A technical report is now being prepared to cover the pressure-distribution tests on biplanes showing the arrangements giving the best lateral and longitudinal stability.

The National Advisory Committee for Aeronautics has recently obtained an autogiro and an airplane fitted with slots and flaps, both to be used in extensive researches involving tests in the new full-scale wind tunnel as well as in flight.

Maneuverability—The investigation of maneuverability has been combined for the greater part with the study of loads in various maneuvers; the angular acceleration, angular velocity, and flight path being obtained whenever possible. A special program of testing on the Corsair observation-type airplane has been completed for single control movements, and the effects of simultaneous control movements are to be investigated in the second part of the program.

Theoretical aerodynamics.—The laboratory staff at Langley Field has completed several important theoretical investigations during the past year. The most important of these is a simple and exact method of calculating the lift or pressure distribution on thin wing sections. It was demonstrated by theory and verified by wind-tunnel tests, that the total pressure distribution consisted of two parts, one a basic distribution for each section and the other the same for all sections. The practical applications of these data enable accurate estimation of pressure-distribution curves.

A solution has also been obtained for the theoretical potential flow around bodies of airfoil form for any attitude, by an expression containing parameters that are functions of the form only. The graphical solutions by this method are particularly simple and convenient for streamline forms.

A study of the effect of boundaries of a finite stream on the flow past an airfoil in the stream has shown that it is possible to devise three new types of wind tunnels having superior characteristics in regard to minimum or zero value of the wall-interference correction.

Airfoils.—A series of 96 airfoils with systematic variation in thickness, mean camber, and position of maximum thickness is now being tested in the variable-density wind tunnel. Tests have been completed and data released for publication on about half of the series. It is of interest to note that some of these are distinctly superior to the best commonly used sections. The information supplied by this investigation when completed will enable accurate prediction of the full-scale characteristics of new airfoils.

The complete verification of the data from the variable-density wind tunnel has led to an insistent demand from the industry and the air services for full-scale data on all standard sections. Before the tests being made for this purpose were completed, changes in stress-analysis methods were found to be necessary from the analyses of the flight tests of the National Advisory Committee for Aeronautics pre-

viously mentioned. These changes required data from maximum negative to maximum positive lift, so that it has been necessary to extend the original program to cover the required negative-lift range. The extended tests have now been completed for practically all widely used sections and the data are being released for publication.

In view of the desirable stability characteristics of the M-6 and CYH sections, the Navy Department suggested that certain well-known sections be tested with their trailing edges reflexed to give stable moments. It was found that all of the sections gave practically identical characteristics when reflexed comparable amounts.

Several other airfoil investigations of less general interest and importance have been completed during the past year.

Propellers.—During the past year the investigation of propellers has been incidental to the wing-nacelle investigation. Most of the tests completed to date have been for tractor arrangements, but pusher and tandem arrangements are to be tested during the next year. While these tests are not concerned primarily with the propellers it is believed that the propulsive efficiency and similar data being obtained are of the greatest practical value to the airplane designer.

Tests have been made with a number of locked propellers and idling propellers during the wing-nacelle investigation. It has been definitely shown that the propeller has practically no effect on lift in either condition, but that an uncowed radial air-cooled engine located directly in front of the leading edge causes a large loss in lift.

In investigating propeller characteristics at high tip speeds, the velocity and direction of the air flow in the rear of the propellers were measured. From the data obtained the thrust and torque along the blades of the propellers have been computed and the results show clearly the part of the blade most affected by high tip speeds.

Ice formation.—The research on the prevention of ice formation has been continued with studies of heat transmission from airfoil surfaces in the refrigerated wind tunnel and in flight. It was found necessary to heat only the front portion of the wing and the quantity of heat needed for complete prevention is small. A vapor heating system utilizing the heat from the exhaust gases has been tried in flight and found to offer considerable promise.

A study has been made of gas-tank vents to find a form that would be immune to closure from ice formation. Both the size of the tube and its orientation were found important, certain combinations being free from blocking by ice. These results have been published.

AIRCRAFT ENGINES

The need still exists for the development of an aircraft power plant delivering approximately 1,000 brake horsepower. The military services are cognizant of this need and have undertaken the necessary development work to produce a 1,000-horsepower liquid-cooled aircraft engine.

The power output of present aircraft engines is continually being increased as better fuels are developed, which permit operation without detonation at higher compression ratios. The elimination by improved design of hot spots in the engine cylinder heads, and the use of exhaust valves having the head and stem filled with sodium, have also contributed to the permissible increase in compression ratio. Several commercial air-cooled engines have been designed to operate at a compression ratio of 6. With a V-type engine designed to use ethylene-glycol cooling, satisfactory tests have been made by the Army Air Corps at a compression ratio of 7.3. This type of power plant appears to be capable of developing large power outputs without cooling difficulties.

Increasing the engine rotative speed and increasing the weight of charge taken into the engine cylinder have also been used to increase the engine power. Boosting tests conducted by the committee show that a net gain in brake mean effective pressure of approximately 5 pounds per square inch can be obtained for each inch of mercury increase in carburetor pressure above atmospheric pressure. To obtain greater pressure in the inlet manifold on radial air-cooled engines, the impeller gear ratio has been increased from 6 to 12. The higher engine speed has necessitated the use of propeller reduction gearing in order to obtain good propeller efficiencies.

The construction of double-row radial air-cooled engines is another solution of the problem of greater engine power. The greater number of engine cylinders gives smoother operation and less engine vibration. This type of engine is being developed by two aircraft-engine manufacturers.

To obtain better fuel distribution, which results in increased power, decreased fuel consumption, and more rapid acceleration, attention is being given to the development of fuel-injection systems to replace the carburetors on present aircraft engines. The fuel systems are designed for the injection of gasoline, either into the inlet manifold or directly into the engine cylinder. Since the air densities into which these gasoline sprays are injected are approximately atmospheric and the time available for injection comparatively long, low fuel-injection pressures may be used. The committee's investigation of fuel-spray characteristics has been extended to include the determination of the spray characteristics of gasoline for

injection pressures of 100 to 500 pounds per square inch.

The use of the N. A. C. A. and the Townend ring types of cowling for radial air-cooled engines has increased to such an extent that almost every radial air-cooled engine installation above 300 horsepower is equipped with some form of one of these cowlings. Consideration has been given to possible methods of cowlings radial engines more completely and admitting only enough air through an opening in the cowlings for efficient cooling. The remarkable endurance and speed records made by commercial airplanes indicate that engine reliability is not being sacrificed for increased power. The radial air-cooled engine still continues to be the most popular type of aircraft power plant for power outputs below 600 horsepower.

The use of ethylene glycol as a cooling agent for aircraft engines continues to be sponsored mainly by the Army Air Corps. There has been, however, one commercial 6-cylinder in-line inverted engine constructed to use ethylene glycol in a sealed cooling system. Although steam cooling is used extensively in England, little interest is shown by our engine manufacturers in this method of cooling.

The problem of reducing the noise from aircraft is being given considerable study both by the committee and by commercial aircraft manufacturers. The committee has devised a fundamentally new method of sound-frequency analysis which has led to the development of a sound analyzer for use in this work. A number of tests have verified the value of this new instrument. The aircraft manufacturers have directed their efforts to muffling the engine exhaust, to decreasing engine vibrations, and to insulating the cabins of commercial airplanes so as to improve the comfort of the passengers.

By breaking the world's nonrefueling endurance record for airplanes, the Packard aircraft Diesel engine has demonstrated that the decreased specific fuel consumption obtained with this type engine is an important factor in making long-distance flights. The company is already engaged in developing a more powerful engine of this type.

Considerable interest is being shown by some engine manufacturers in the radial air-cooled 2-stroke-cycle compression-ignition engine. An investigation of the factors influencing the performance of this type of aircraft engine is being conducted at the committee's laboratory.

The development of hydrogenated "safety fuels" having high flash points for use in present carburetor aircraft engines would seem to hold considerable promise as a possible means of reducing the fire hazard in aircraft. The present safety fuels tested by the committee can not be successfully carburetted. To overcome this difficulty the committee is investigating

the performance obtained from these fuels when sprayed directly into the engine cylinder. The results obtained on a single-cylinder carburetor-type engine show that with the optimum injection rate used in the tests the power output with the safety fuel having a flash point of 120° F. was equal to that obtained using a carburetor and gasoline, although the fuel consumption was from 5 to 8 per cent greater with the safety fuel.

STRUCTURAL MATERIALS

The outlook for aluminum alloys appears more promising from the standpoint of their utilization in aircraft than it has been at any time in their history, especially with reference to making their use more dependable and certain.

The development of the high-frequency fatigue-testing machine for the determination of the endurance limit of metals was a pioneering effort and has greatly reduced the time required for such an investigation. Heretofore it required nearly 300 days to make an evaluation of the fatigue limit of nonferrous alloys, while with the present equipment an evaluation can be made in approximately 30 days. The tests so far conducted with this machine have demonstrated that frequencies of reversal up to 12,000 per minute, which is very high as far as testing is concerned but within the possible range encountered in practice, give approximately the same results as frequencies of 1,200 per minute previously used.

A new situation has arisen in connection with the endurance properties of aluminum alloys. The heat-treatable and heat-treated alloys now in use have endurance limits of approximately 25 per cent of their tensile strength. This is relatively small, and work in the direction of increasing the tensile strength to increase the endurance limit seems to meet with only moderate success. For instance, raising the tensile strength 10,000 pounds per square inch increases the endurance only 2,000 pounds per square inch.

With the other aluminum alloys, the endurance limit is approximately 50 per cent of the tensile strength, but the tensile strengths are only 50 to 75 per cent of that for duralumin. This situation suggests a division of materials with reference to their uses. Where high yield point is especially demanded, stronger materials will naturally be called for, but where endurance limit is a critical factor it is very probable that an alloy of lower tensile strength will be used.

Regarding the question of coatings for corrosion resistance, it may be said that marked progress has been made both in the anodic processes and in the protective films themselves. Some samples, after a year's exposure to salt sprays, show practically no deterioration of the physical properties of the metal,

and look about the same as they did before the test. Since it has been definitely shown that corrosion reduces the fatigue limit of metals, anything which can be gained in resistance to corrosion is a gain in the structure itself. This has been satisfactorily demonstrated in connection with Alclad. Alclad may not have quite as high tensile properties as plain duralumin, but if given a year or two in service the retention of its original physical properties shows it to be ultimately superior.

Aluminum alloys having high strength at high temperatures for use in engine parts such as cylinder heads are being developed. One of these alloys which will be available for tests in the near future has a tensile strength at 600° F., 25 per cent greater than the alloys now in use. Progress in the forging art has been very rapid in the last year or so and the number of engine parts fabricated by dies and forging has gradually increased. The quality of forged propeller blades has shown marked improvement.

In the aluminum-casting field four or five different alloys are under development that appear from preliminary tests to be resistant to salt-water corrosion and at the same time lend themselves to both foundry and plant manufacture to a satisfactory degree.

Stainless steel in aircraft construction is still being investigated both in the laboratory and under actual service conditions. Its use in engine exhaust manifolds, wing ribs, seaplane floats, control cables, struts, and streamline wire has proved satisfactory and has met expectations with reference to its corrosion-resistance properties. In the case of streamline wire the progress has been such as to warrant the placing of fairly large production orders with the manufacturers, with the result that the manufacturers have been able to improve their methods of fabrication and increase the quality of the product at least 50 per cent.

Beryllium and its alloys still hold considerable interest on account of their higher strength-weight ratio in comparison with aluminum alloys. However, the art of producing this material has not sufficiently developed to bring its cost of production within a range to attract attention as a structural material for aircraft.

Although wood and textiles are used to a considerable extent in both military and commercial aircraft, they do not present the diversity of problems which metals do, nor do they lend themselves to improvement in their mechanical properties to any appreciable degree. However, close attention to the fabrication of mechanical cloths for use as wing coverings, gas-cell and airship cloths, and parachute cloths, has resulted in improvement in such properties as strength-weight ratio and resistance to tear.

AIRSHIPS

Airship progress during the past year has been marked by one outstanding event, namely, the completion and satisfactory trials of the U. S. S. *Akron*. This airship of 6,500,000 cubic feet volume (helium) was contracted for by the Navy Department in October, 1928; erection of frames was started in November, 1929; and the airship was completed and ready for trials in September, 1931. Trial flights amounting to approximately 100 hours were successfully carried out within a period of four weeks and the airship was thereupon accepted by the Navy Department and commissioned as a United States naval airship.

The U. S. S. *Akron* represents a complete new design of airship conceived and built entirely within the United States. This fact is significant because it means the establishment within the borders of the United States of an industry capable of meeting probable demands, military or commercial, as to construction of airships.

The design of the U. S. S. *Akron* embodies a number of features which either are entirely new, or are new in their present form, to airship construction. Some of the more important of these features are:

- A somewhat lower fineness ratio than used in former practice.

- Inherently stiff main frames as compared with the wire type of main frames heretofore used.
- Easier and better access to all parts of the interior of the airship for inspection purposes and to facilitate repairs in flight.

- An internal hangar for housing airplanes.

- The elimination of the pendant external power cars in favor of internal engine rooms.

- An "in-line" arrangement of propellers, four propellers on each side.

- Propellers suspended from outrigger struts with means for tilting each propeller through an angle of 90°. This provision for tilting combined with the reversibility of the airship engines gives the possibility of obtaining thrust in four directions.

- The provision of a transmission shaft between engine and propeller, the design of this transmission shaft being unique in aeronautical practice.

- The provision of a "skin-type" condenser for water-recovery apparatus.

- The use of improved type of fabric for gas-cell construction and the abandonment of the gold-beater's-skin type of fabric heretofore used.

- The use of combined automatic and manually operated gas valves.

- The use of resilient-wire bulkheads for checking the surging of gas cells in case one is deflated.

The use of special materials in the construction of the airship, notably an aluminum alloy which has been subjected to a slight degree of cold rolling after heat treatment, thereby raising the yield point of the material at the expense of a slight reduction in elongation; and special high-strength hard-steel wire galvanized before the last drawing operation.

Special attention to protection of all metal parts against corrosion.

Increased strength factors.

The final results from the trial flights of the U. S. S. *Akron* have not been completely evaluated, but enough has been learned to warrant the belief that the airship design is fundamentally sound. A new set of propellers will be required before the maximum possible speed of the airship can be attained.

The second airship included in the airship program of the Navy Department, for which contract was made at the same time as that for the U. S. S. *Akron*, is scheduled for completion about January, 1933.

The material condition of the U. S. S. *Los Angeles*, as revealed by periodic inspection and check tests of representative samples, continues to be satisfactory.

Operations of small airships of the nonrigid type have been continued by the Army, the Navy, and by private interests. The performance of these airships in several instances has been noteworthy.

The small experimental metal-clad airship owned by the Navy Department has been successfully operated during the past year. Measurements have shown that superheat is created and lost very rapidly in this type of airship. Tests of samples removed from the hull plating of the airship showed practically no deterioration in the thin metal hull covering after 18 months' operation.

Excellent progress has been made in mechanical ground-handling methods for large rigid airships and warrants the assertion that a satisfactory solution to this important problem is close at hand. The troublesome feature of how to haul the stern of an airship broadside to the wind and hold it there has apparently been solved. A circular railroad track with its center located on the shed axis extended serves as a "turning basin." A long low steel beam mounted on wheels is used to support the stern of the airship, while side guys leading from near the axis of the airship to the ends of the beam serve to restrain the airship against side forces. With the airship thus secured to the stern beam, a powerful locomotive of special design hauls the stern beam around the circular railroad track as desired. When the airship is to be moved in or out of the shed, a second set of wheels mounted on the stern beam is brought into play, and

the airship, with stern beam attached, is moved by a mobile mooring mast at the bow along straight lines of railroad track into the shed. Other pieces of mechanical apparatus, notably winches, yaw-guy anchorages, and mooring-masthead mechanisms, have undergone improvements during the year.

The Government helium plant near Amarillo, Tex., continues to supply increasing quantities of helium at progressively decreasing costs. The problems of re-purification of helium which has become contaminated with hydrogen or with a hydrocarbon fuel gas, are being given careful study. An experimental order has been placed for a new type of helium purity meter which, if successful, should greatly facilitate the taking of helium readings. The instrument is of such type that it can be applied to each individual cell in a rigid airship and will give a continuous record of helium purities.

SUMMARY

There has been continued progress and increased activity in military aviation and commercial air transportation. The demand for aircraft to be used in commercial air transportation may be expected to increase slightly, but not to an extent sufficient to maintain an adequate aircraft manufacturing industry. The volume of production for the Army and Navy has been relatively stable, but there has been a reduction in the manufacture of airplanes for private use. This reduction has been due to various causes, among the most important of which is the fact that the airplane for private use has not been developed to that degree of safety, performance, and economy necessary to bring about its extended use by private owners.

There is a keener appreciation of the increasing relative value of aircraft for military and naval purposes. Because aviation is so vital to the national defense, and because the Government is still the principal customer for aircraft, it is a matter of governmental concern that there should be maintained an adequate nucleus of an aircraft industry capable of expansion rapidly to meet needs in an emergency.

The Government is doing much for the support and development of aviation, but with the expiration of

the original 5-year aircraft procurement programs of the Army and Navy nothing would have such a beneficial effect upon the stability of the aircraft industry as assurance of continuity of Government procurement of military and naval aircraft.

But even this policy, vital as it is to the industry, would merely continue the status quo. It would not solve the fundamental problems confronting aviation in all its branches. In military, commercial, and private aviation there must be improvement in the performance and in the efficiency of aircraft, and in private aviation especially there must be greater safety and greater economy in production, maintenance, and operation costs. Such improvements must come primarily from technical developments which are the result of scientific research. The major problems are to increase the aerodynamic efficiency of aircraft, the operating efficiency of engines, and the control of airplanes at low speeds. Next in importance come the problems of simplifying design and of making possible lower costs of construction, maintenance, and operation.

The committee's research programs embrace all the fundamental problems of military, commercial, and private airplanes, and the committee's laboratories are now well equipped, especially in the field of full-scale investigations of airplanes, propellers, and sea-plane floats and hulls. The committee feels that the support consistently given it by the President and the Congress has been of the greatest assistance in the development of aeronautics in the United States. The results of this support are reflected in the progress of aeronautics.

The committee recommends continued support of its work in the fields of pure and applied research on the fundamental problems of aeronautics, and believes that such continued support will provide the best assurance of further progress in the development of aircraft for all purposes.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS.
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